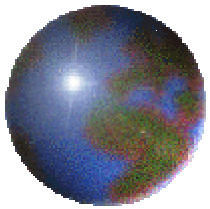


Assessment of Energy Supply Systems with an Energy Infrastructure Model for Asia/Eurasia

Yasumasa FUJII

Department of Electrical Engineering

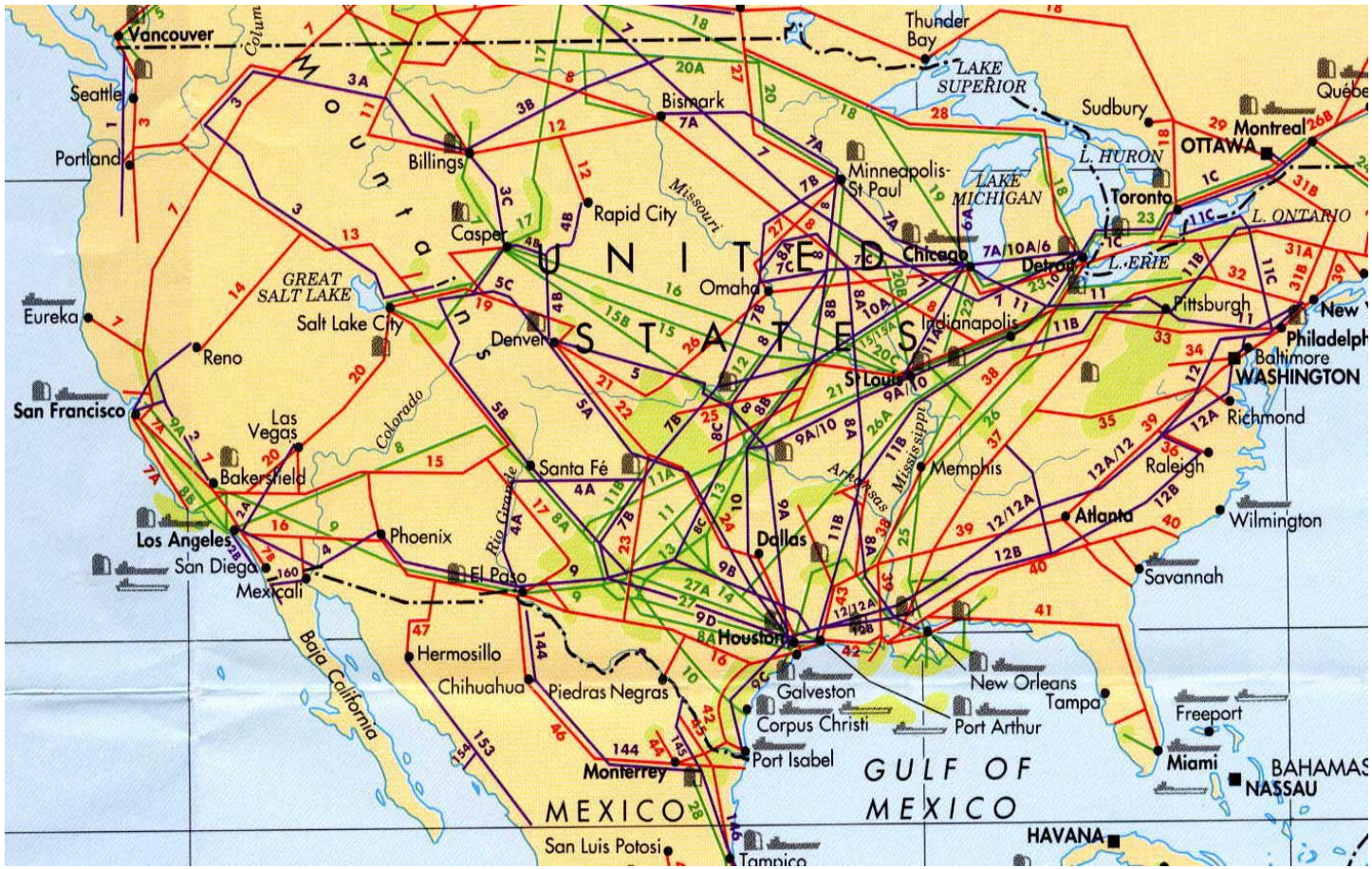
The University of Tokyo

Background

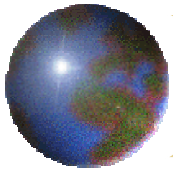
- Rapidly growing energy demands in Asian countries
- Enormous energy resource supply potential in central Asia and Russian far east
- Concerns about the global warming issues due to the increases in the atmospheric CO_2 concentrations
- Future necessity of extensive energy infrastructure development in Asia/Eurasia

Pipeline Network (Europe)

Pipeline Network (North America)

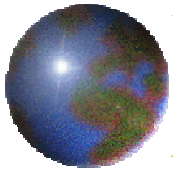


Pipeline Network (East Asia)



Purposes of the Study

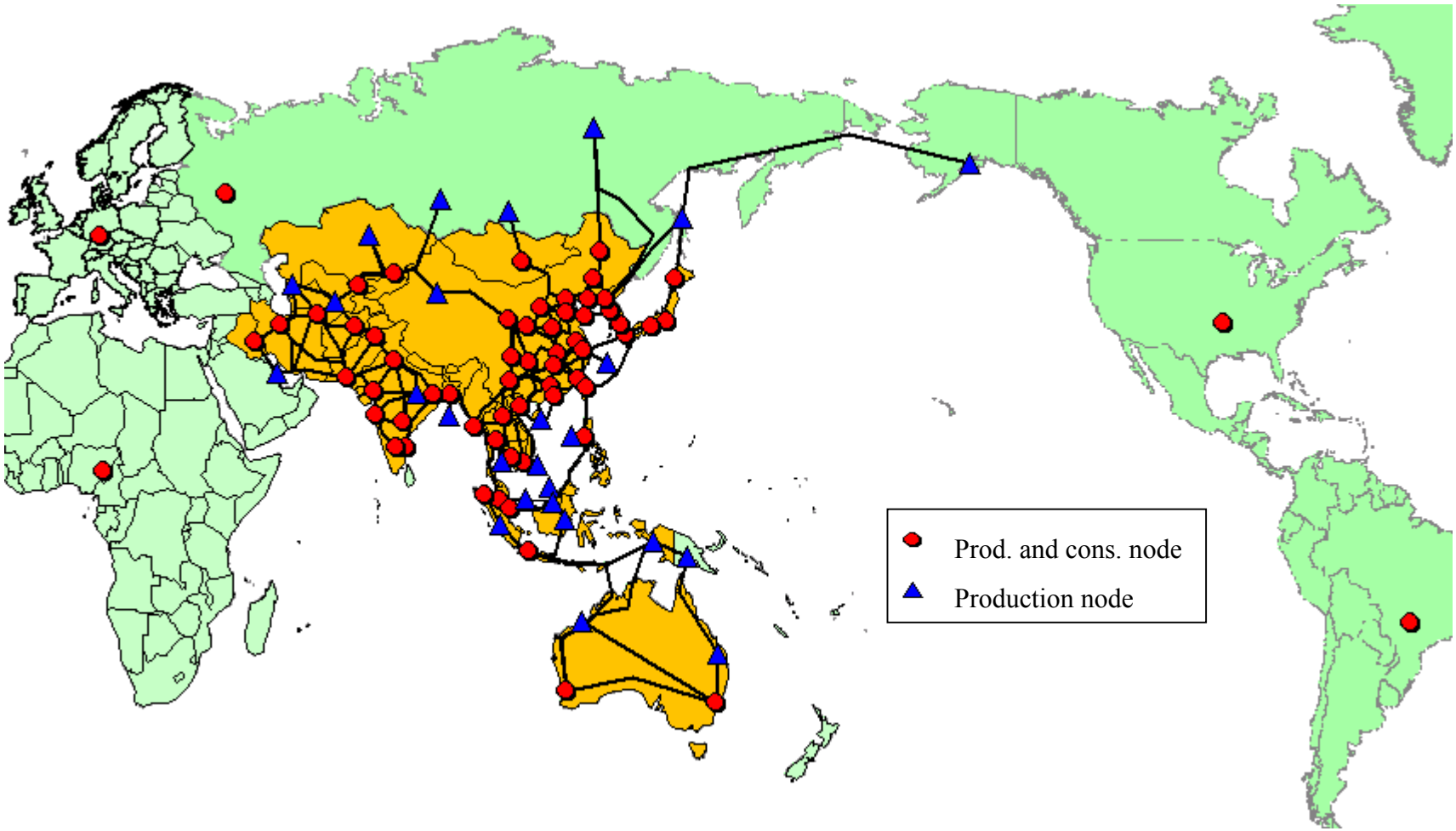
- Development of an energy transportation infrastructure model
- Derivation of the optimal configuration of energy transportation infrastructure for Japan and her neighboring regions
- Evaluation of the role of CO_2 emissions reduction technologies in Asia
- Evaluation of the policy options with investment and CO_2 constraints

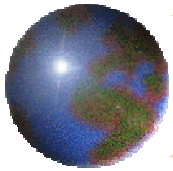


Outline of the Model (1)

- Geographical coverage
  - *The whole world with the detailed geographical description of Asian region*
- Number of representative nodes
  - *89 (major big cities and production sites)*
- Time horizon
  - *Until the year of 2050* (at ten-year intervals)

Nodes and Links in the Model





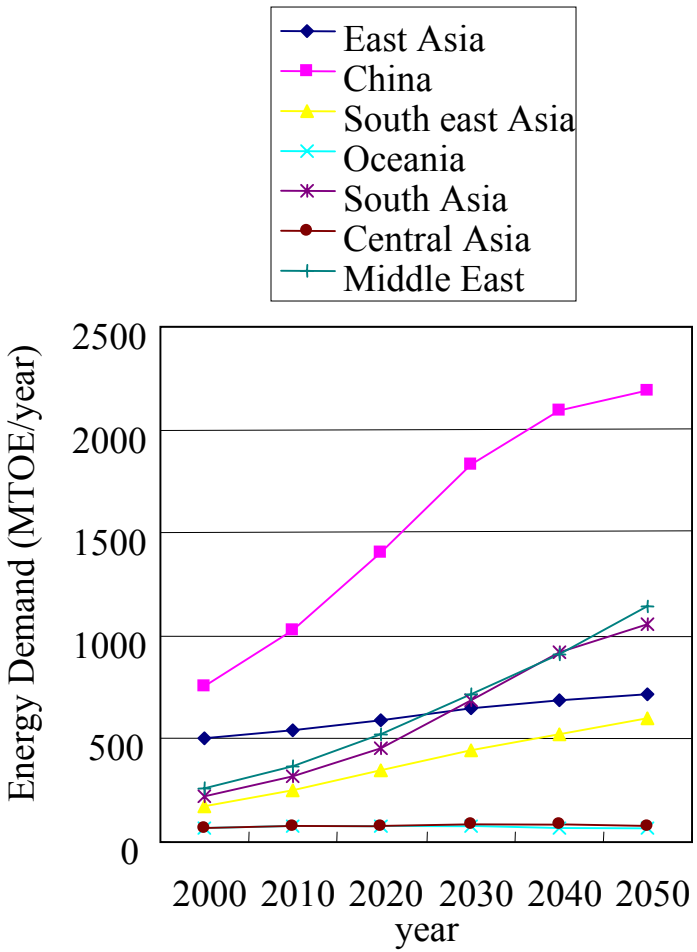
Outline of the Model (2)

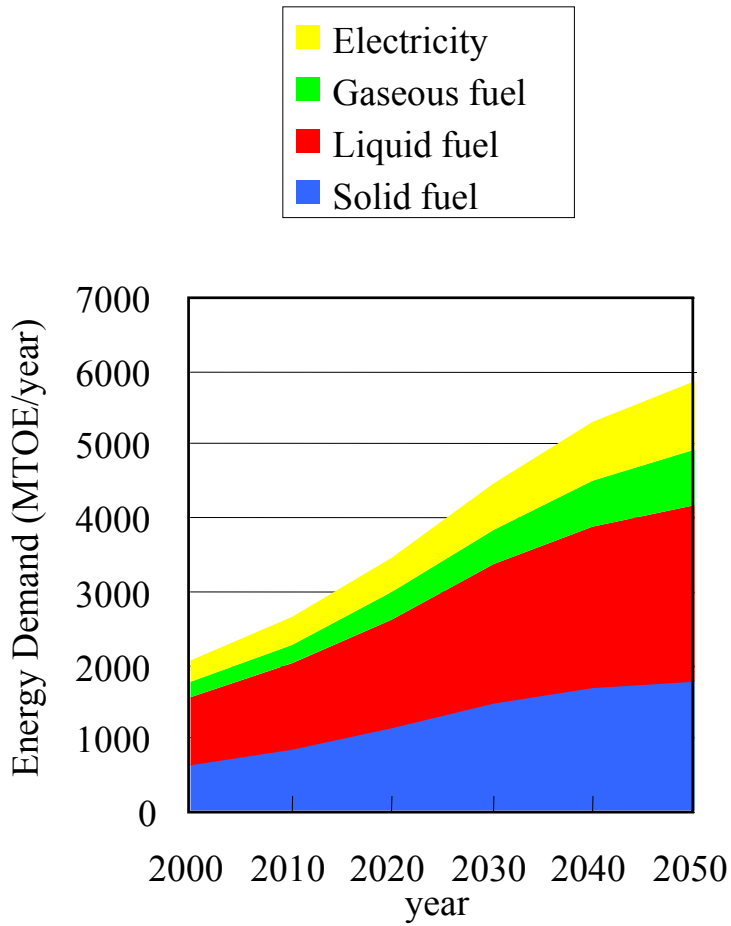
- Energy resources
  - *Coal, Oil, Natural Gas, Hydro and Nuclear*
- Energy transportation
  - *Pipelines, Tankers, Bulk ships, Freight trains and Power transmission lines*
- Energy conversion processes
  - *Electric generation, CH_3OH synth. and H_2 prod.*
- Final consumption sectors
  - *Solid, Liquid and Gaseous fuels, and Electricity*

Outline of the Model (3)

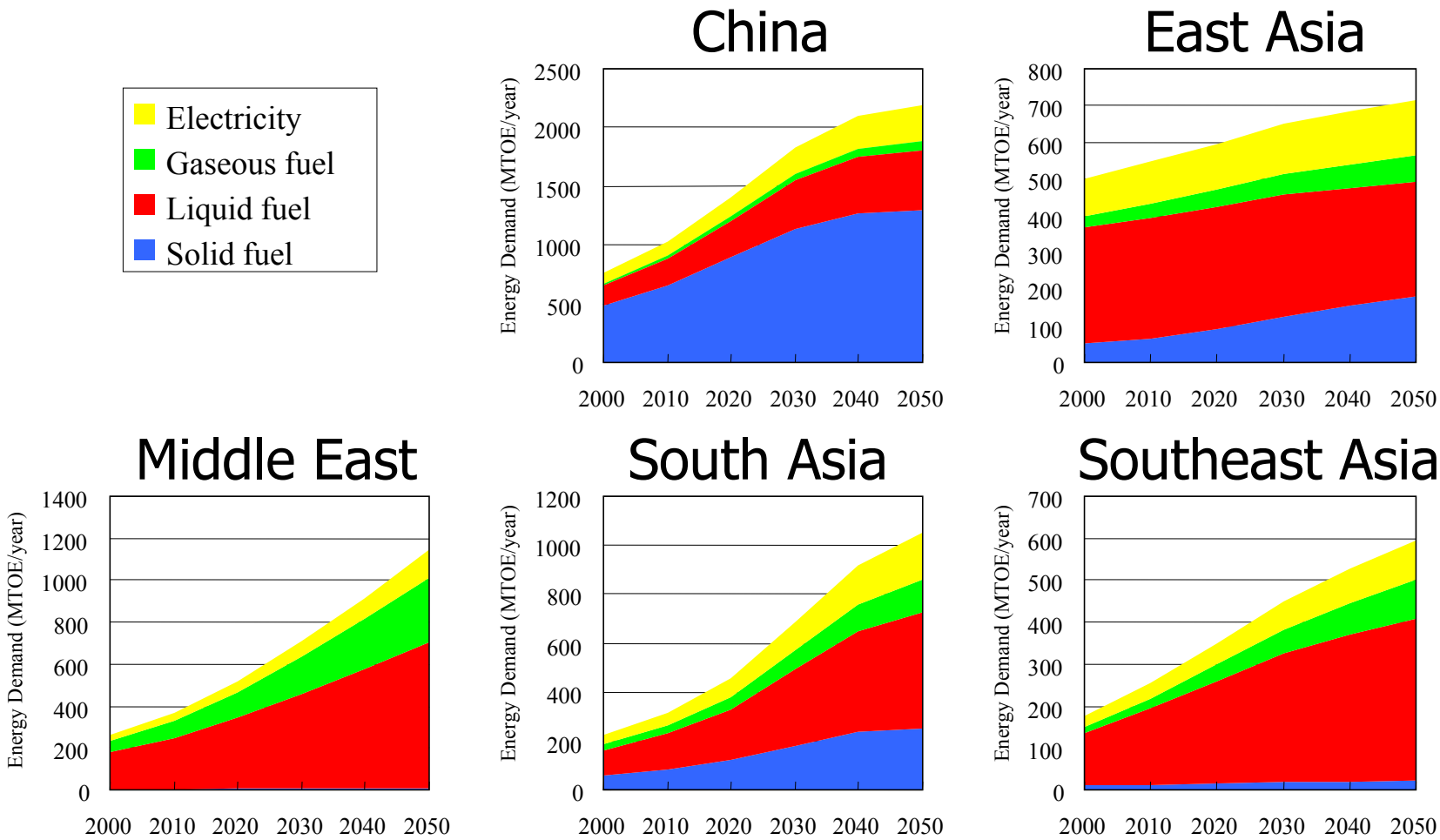
- Dynamic Linear Programming
- Software
  - *Optimization application* **EXPRESS**
- Minimization of the sum of discounted total energy system costs over the simulation period

Energy Demand Scenarios

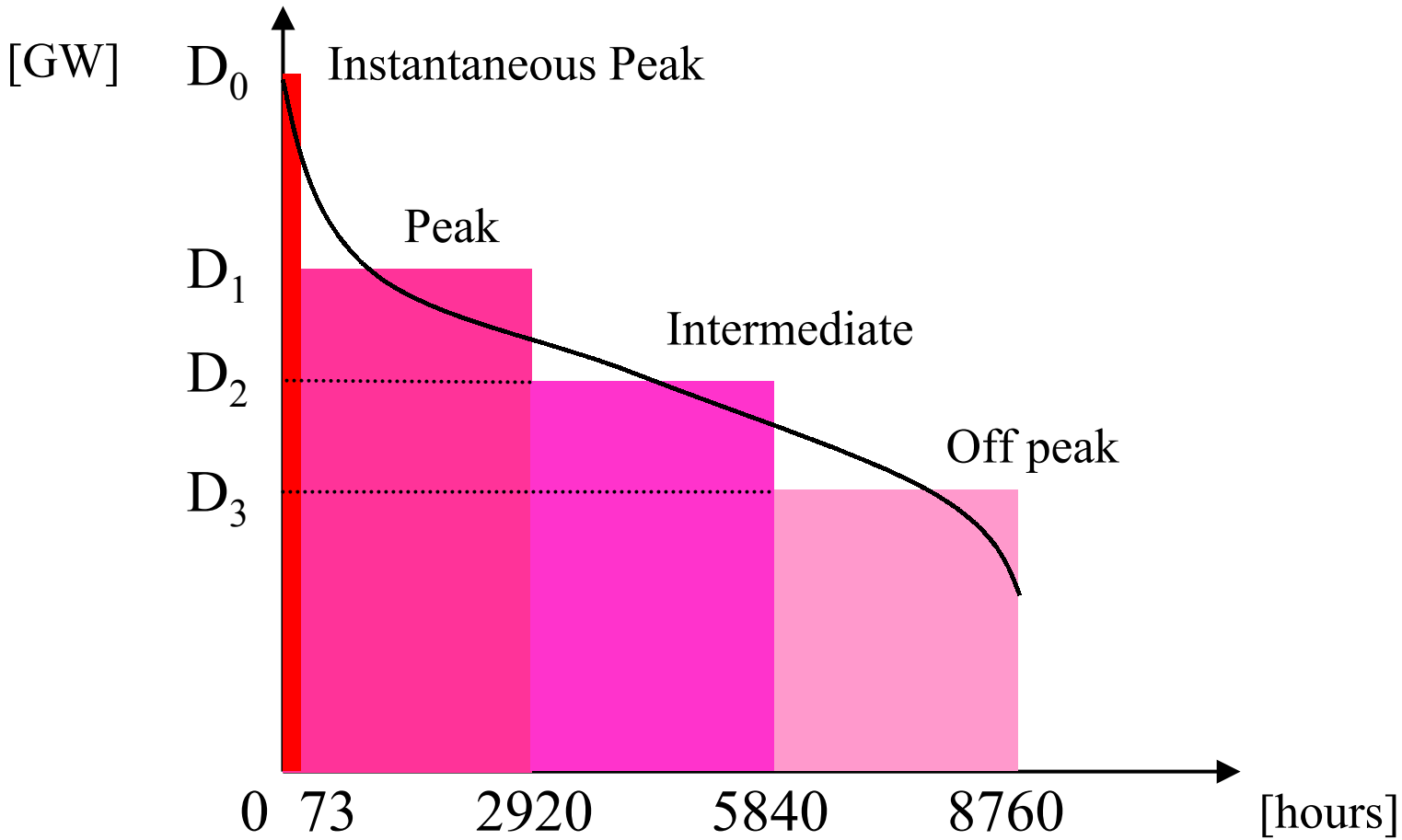




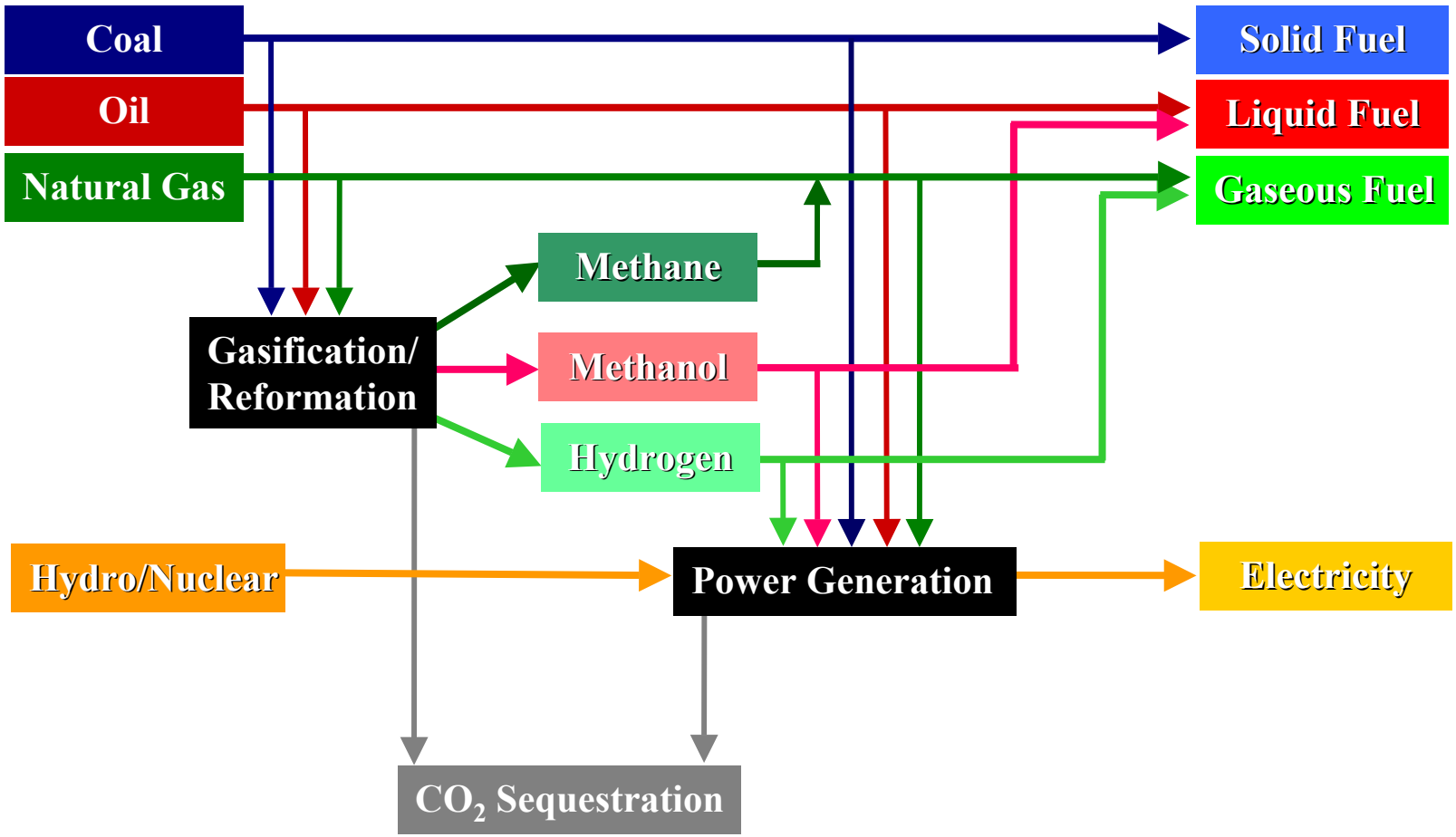
Demand Scenarios by Sub-region



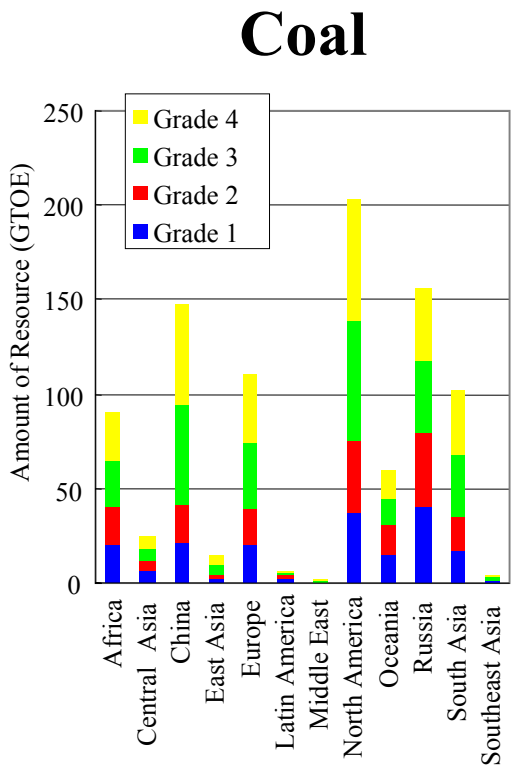
Electricity Demand

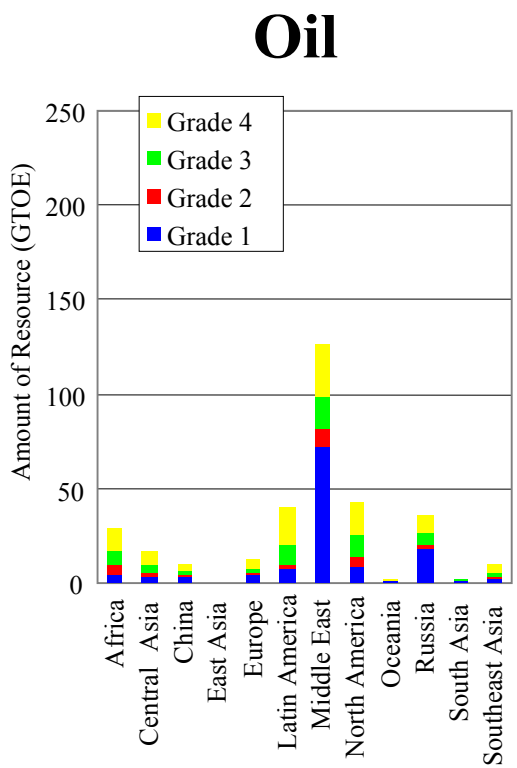


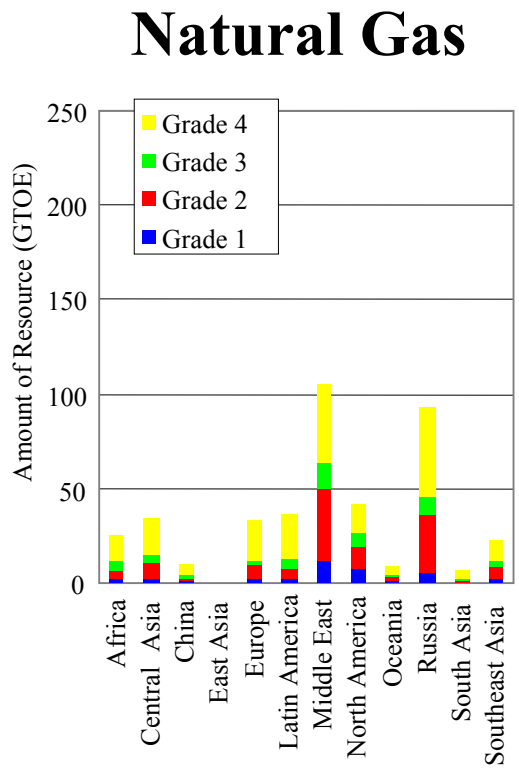
Energy Flow in the System



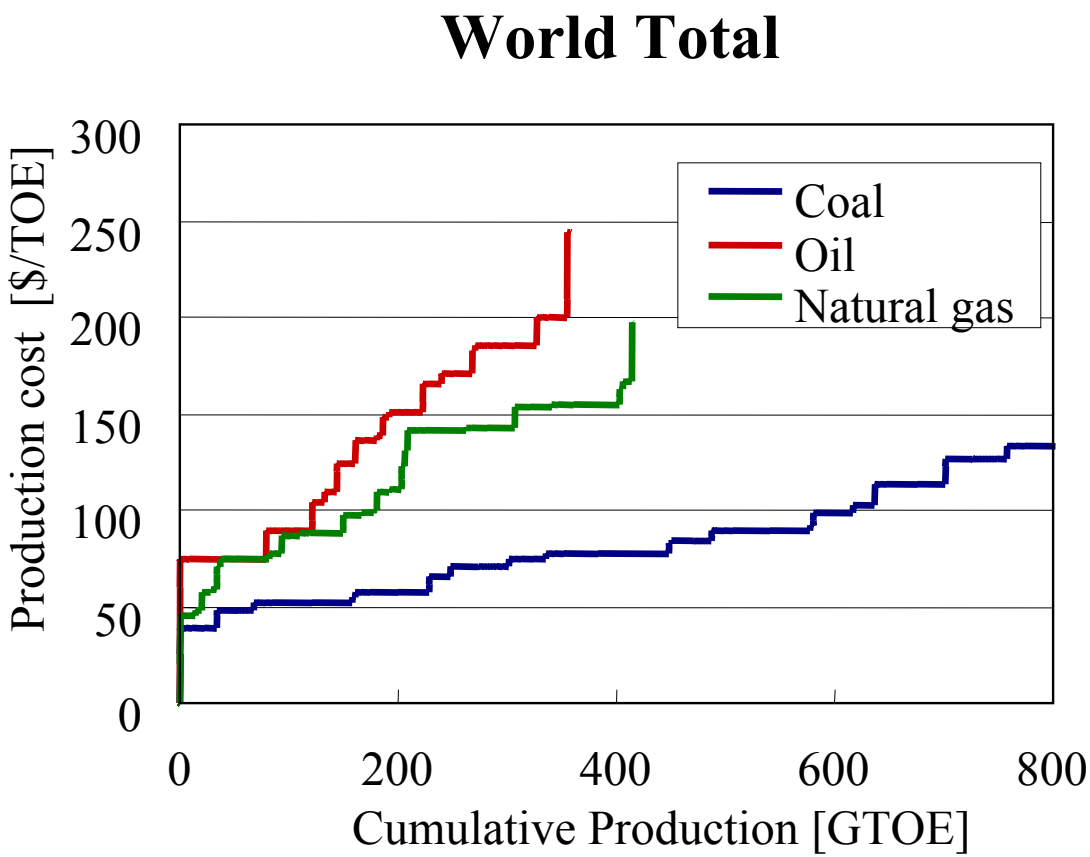
Fossil Fuel Resources







Fossil Fuel Production Cost



Transportation Costs and Losses

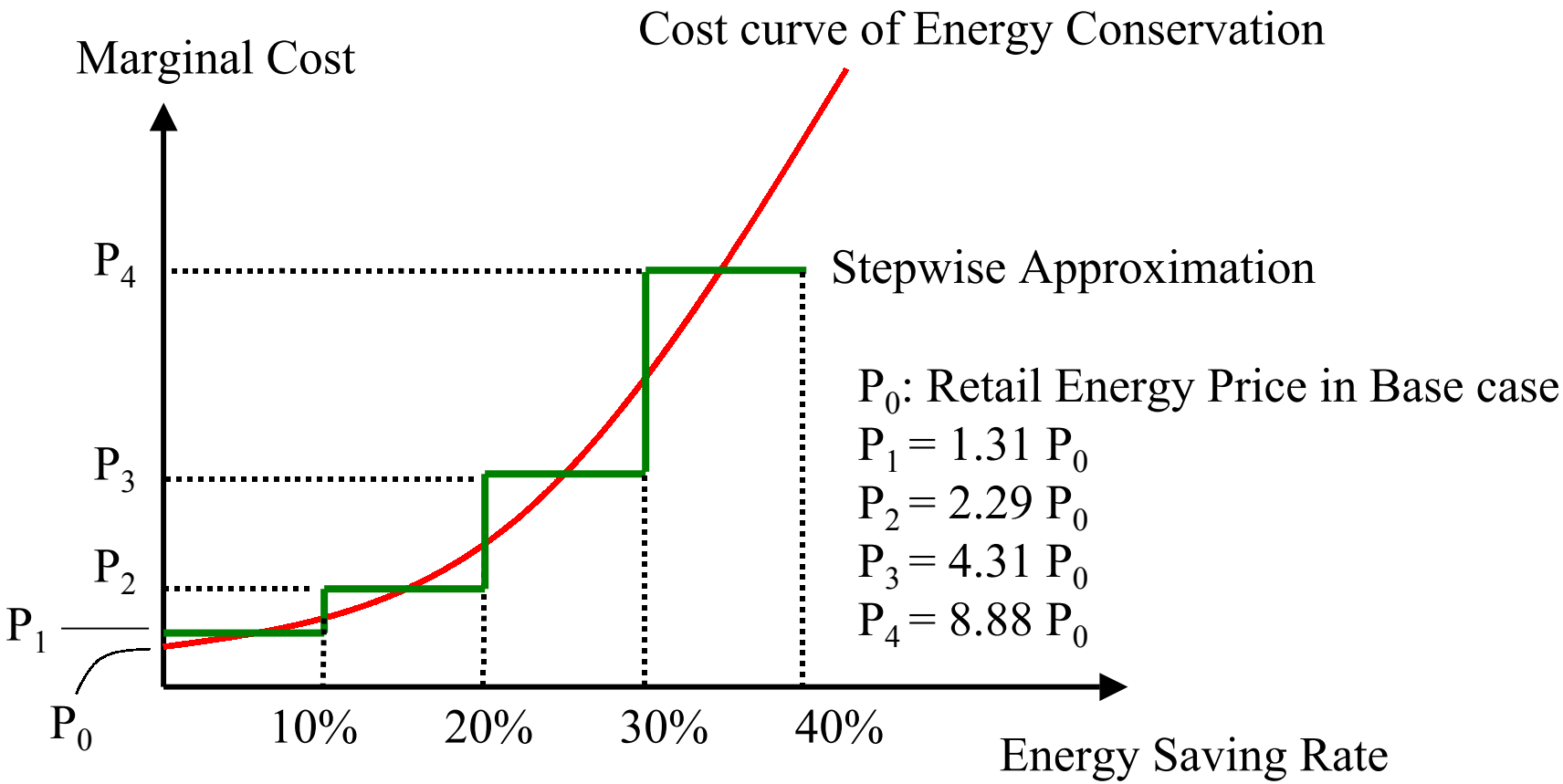
L:Distance [Unit: 1,000km]

	Cost [$/MTOE]	Loss [%]
Coal Freight Train	45.4*L*	2.2**L*
Oil Pipeline	6.2*L*	2.3**L*
Natural Gas Pipeline	22.0*L*	2.3**L*
Methanol Pipeline	12.6*L*	2.3**L*
Hydrogen Pipeline	35.2*L*	3.5**L*
Coal Bulk Ship	0.94*L* +0.78	-
Oil Tanker	0.61*L* +0.5	-
LNG Tanker	6.07*L* +97.6	0.2**L* +7.7
Methanol Tanker	1.23*L* +1.02	-
Liquefied Hydrogen Tanker	13.6*L* +213.8	0.2**L*
Power Transmission [$/kW]	89.7*L* +23.8	10**L*

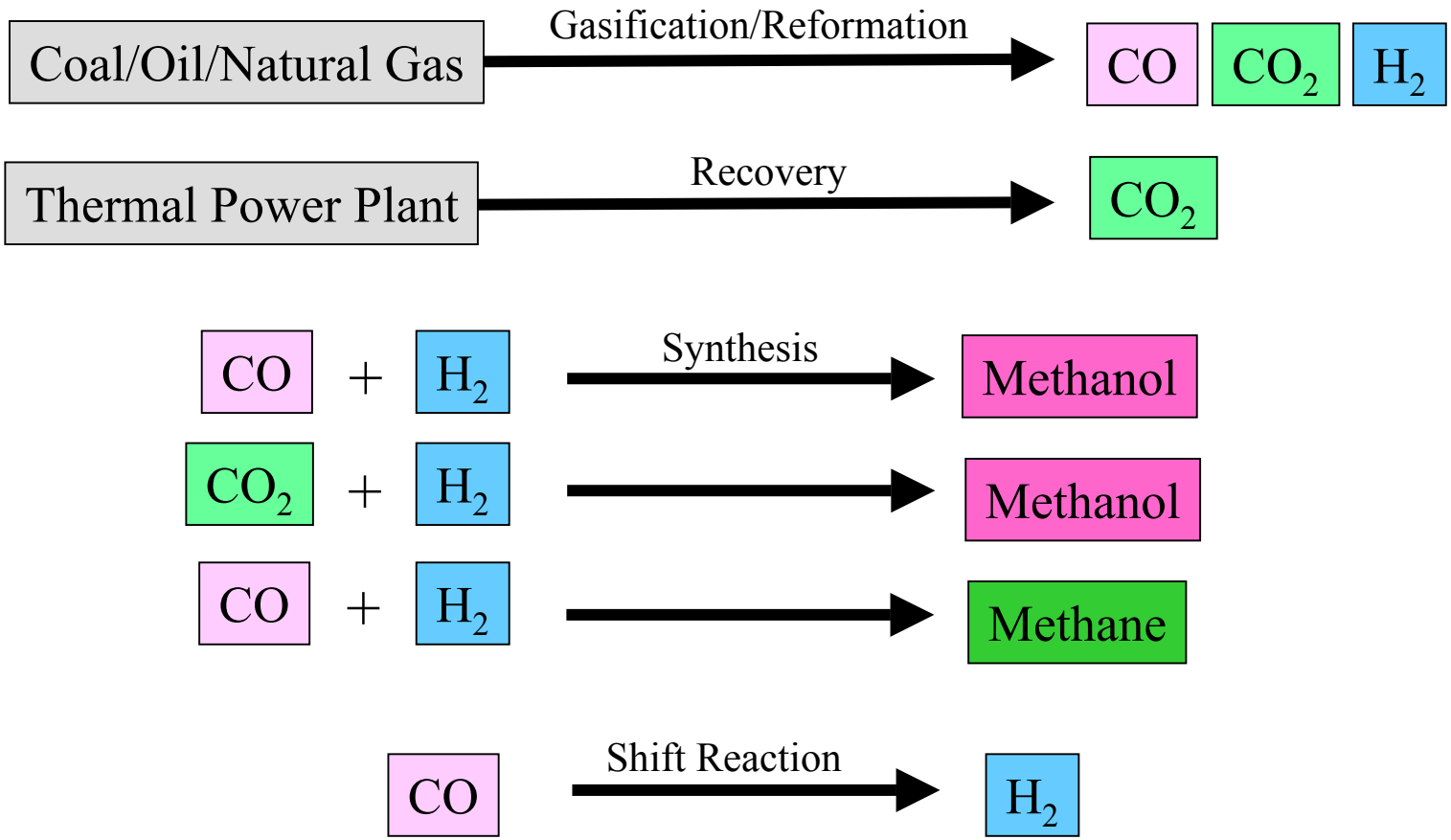
Power Generation Plants

	Construction cost [$/kW]	Thermal Efficiency [%]
Coal fired	1,300	27~39
Oil fired	750	29~43
Natural gas fired	850	34~49
Methanol fired	1,650	33~49
Hydrogen fueled	1,850	32~47
IGCC	2,000	31~46

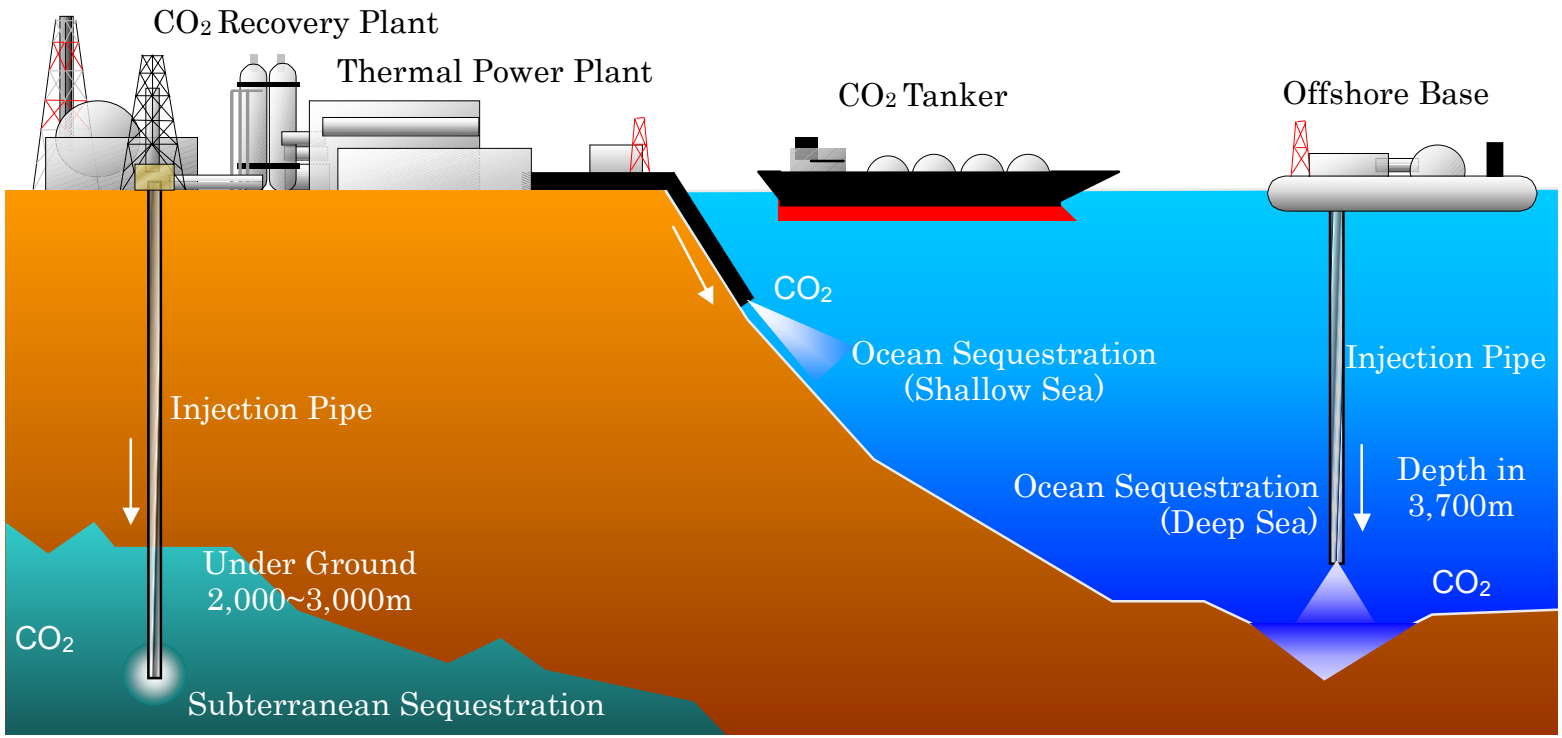
Energy Saving



Chemical Processes



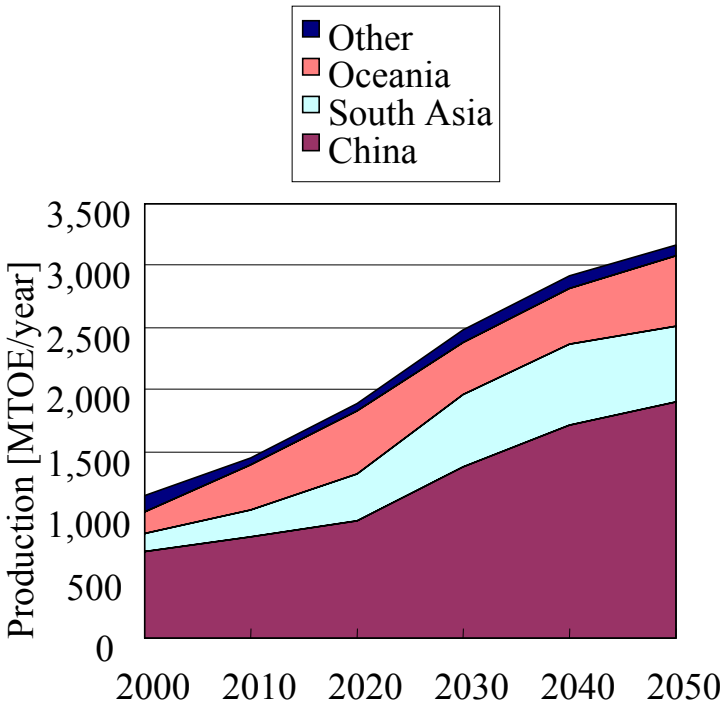
CO_2 Sequestration



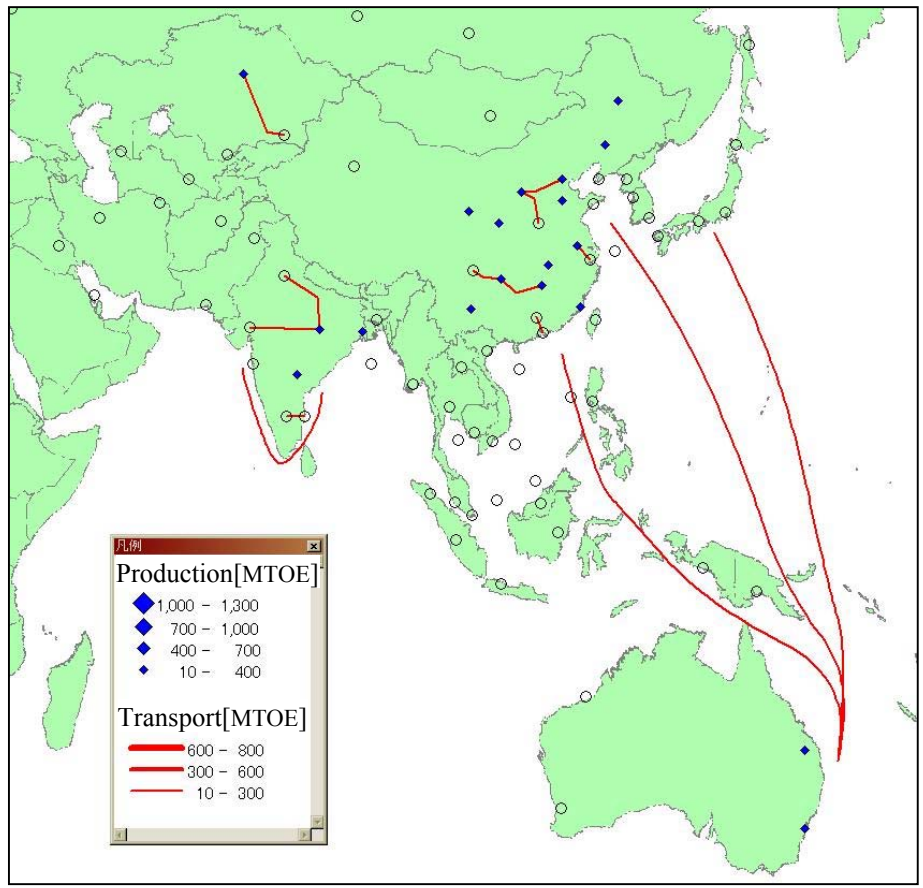
Assumed Simulation Cases

- Business as Usual Case (BAU)
- Investment Constraint Case (IC)
  - *Investment Limit under 0.5~1.0% of GDP*
- CO_2 Constraint Case (CC)
  - *Carbon Taxes of 100~500$/t-C*

Coal (BAU)

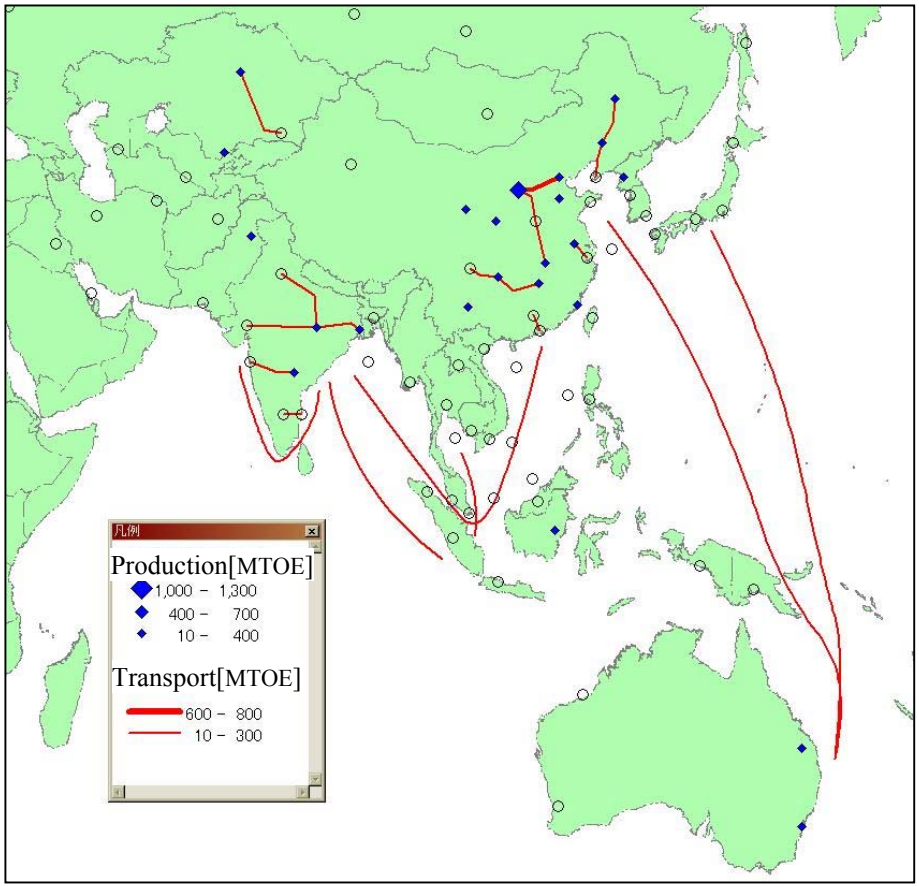


Production Profile in Asia

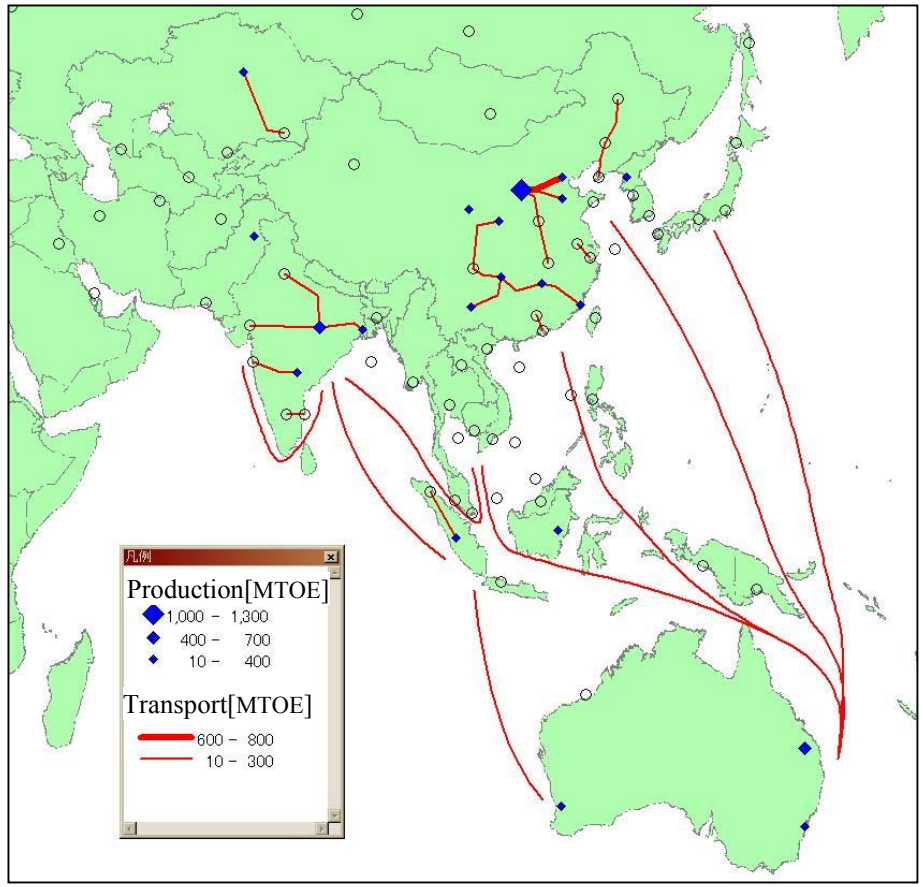


Year of 2010

Coal (BAU)

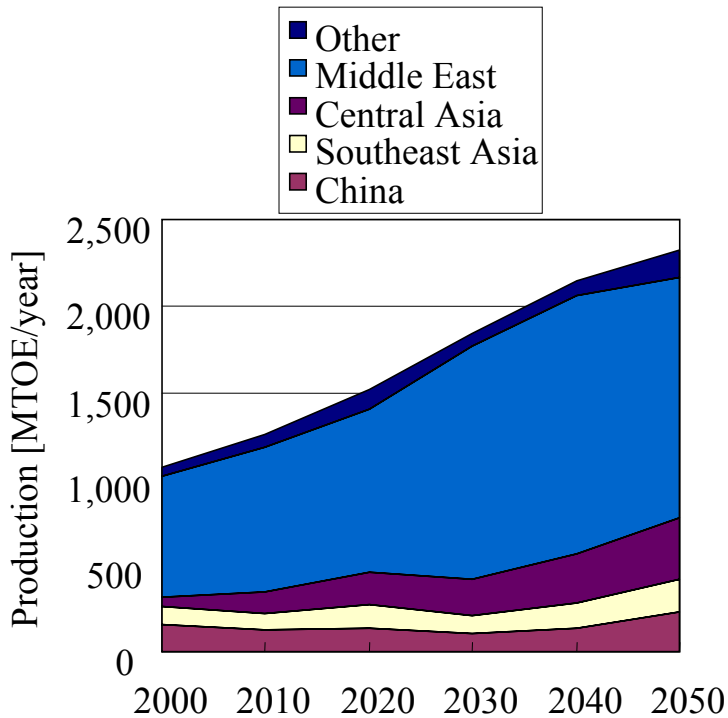


Year of 2030

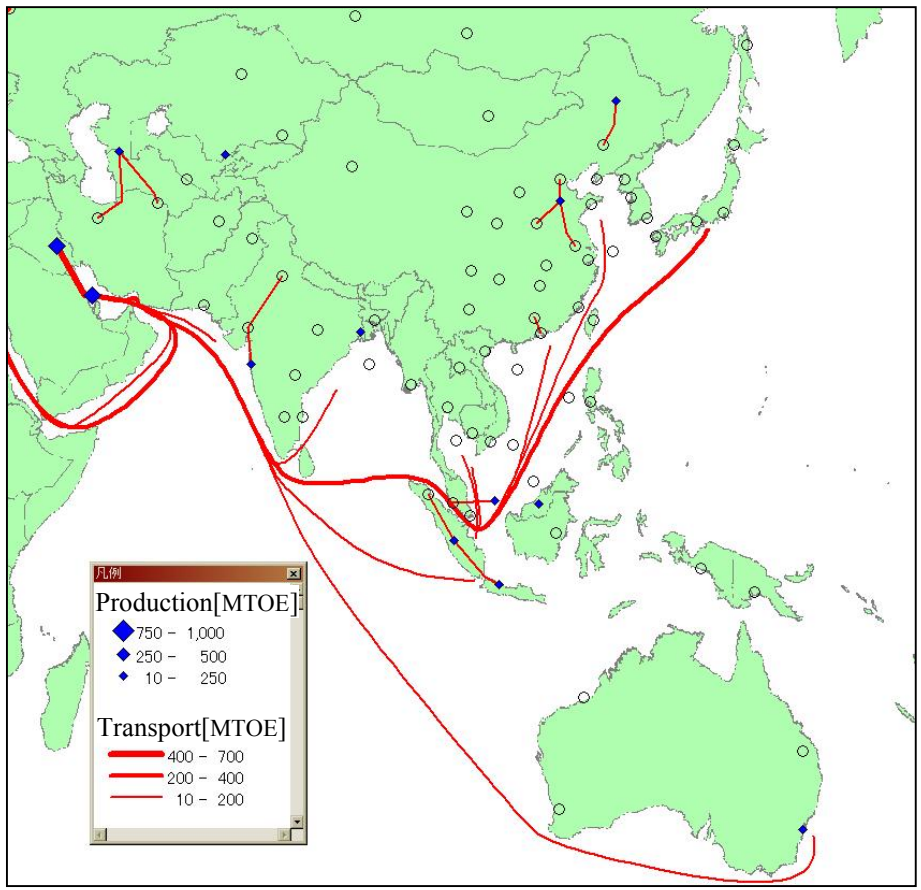


Year of 2050

Oil (BAU)

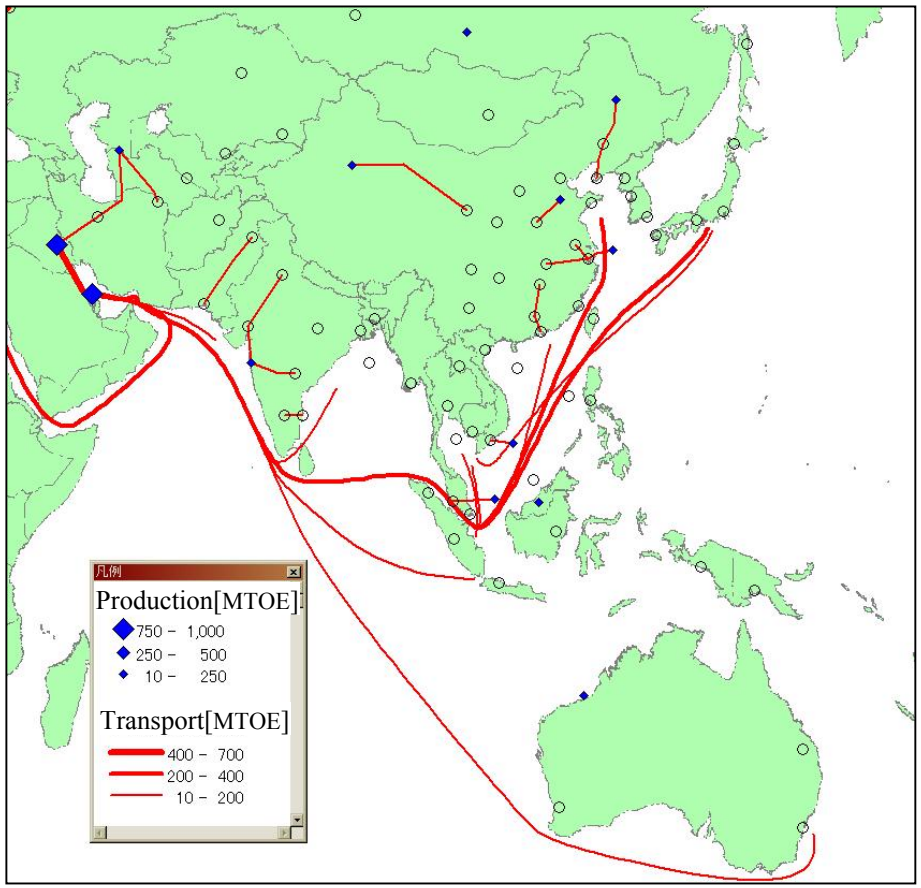


Production Profile in Asia

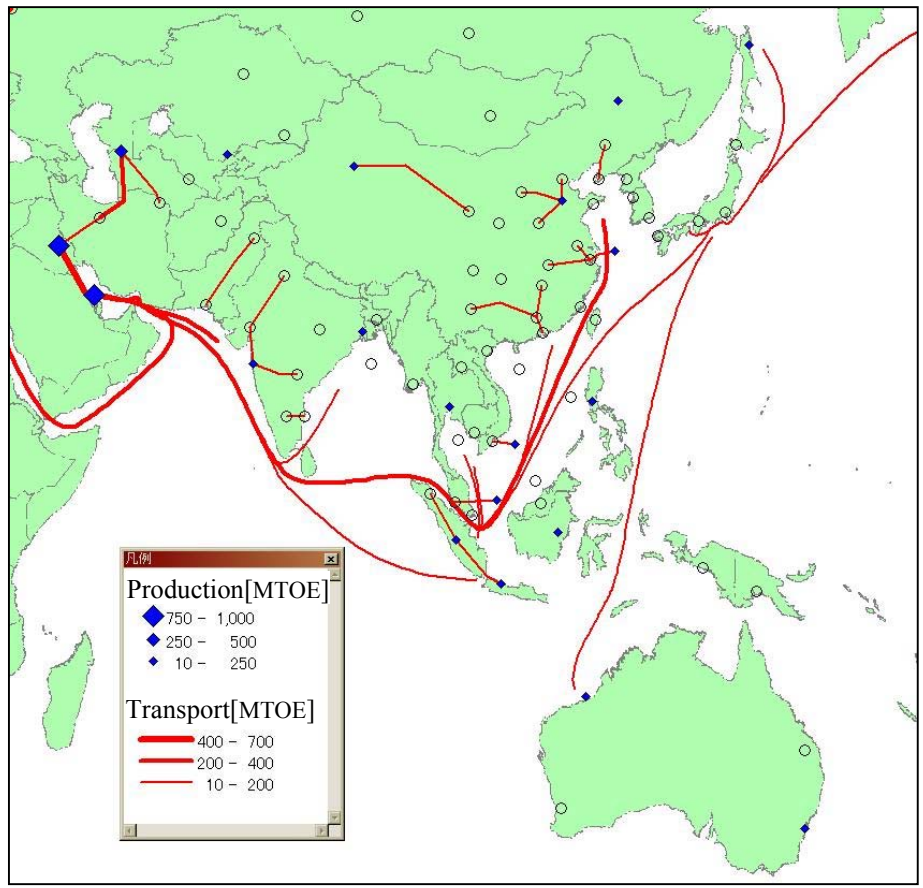


Year of 2010

Oil (BAU)

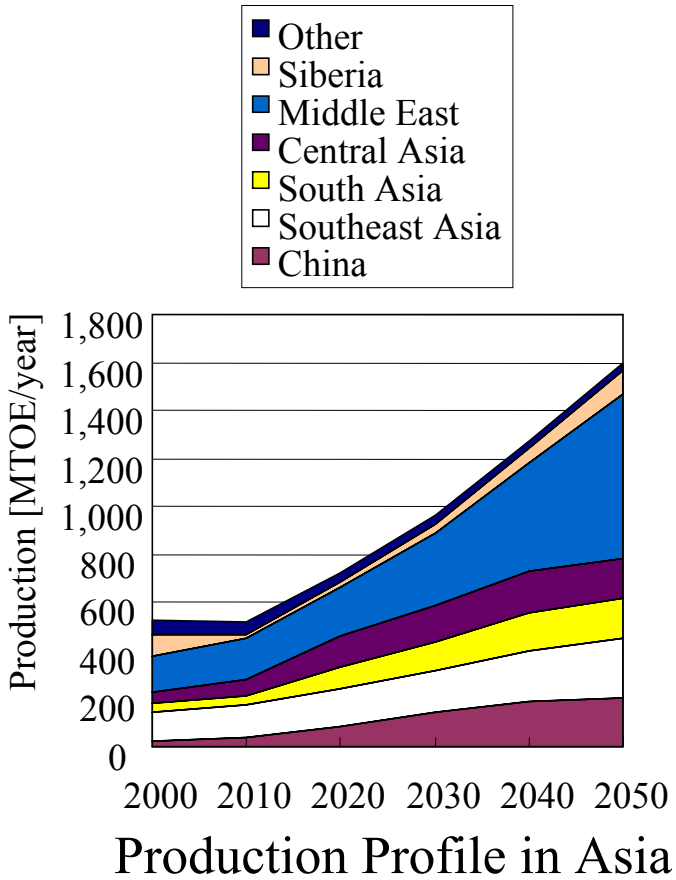


Year of 2030

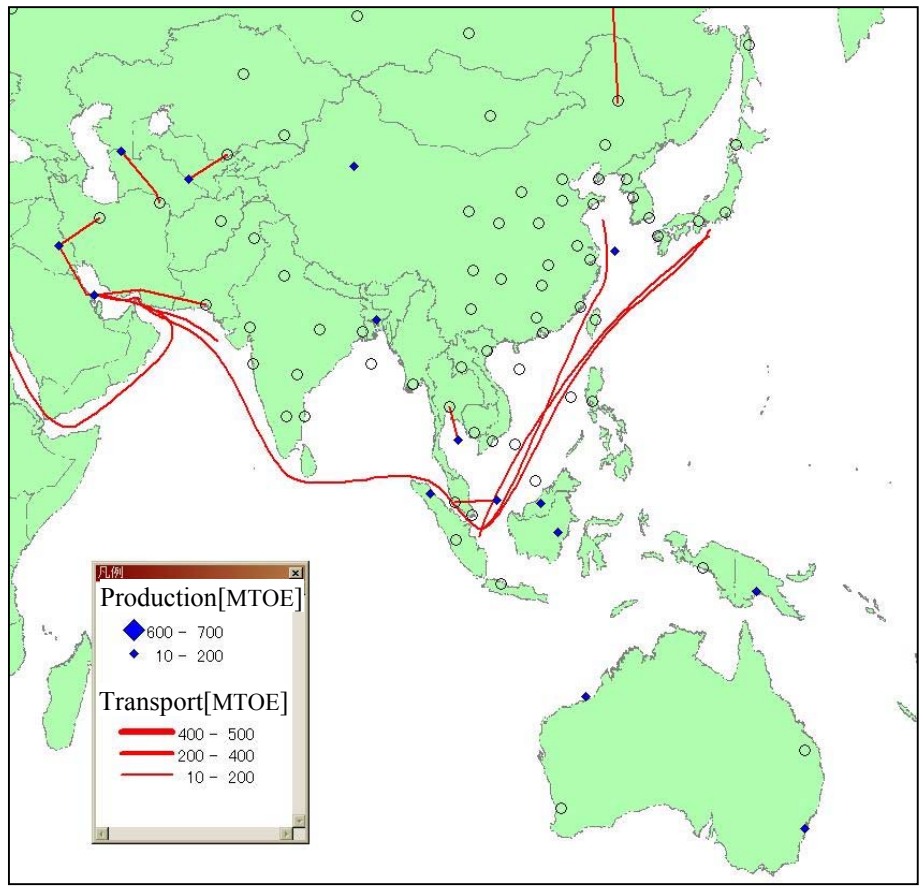


Year of 2050

Natural Gas (BAU)

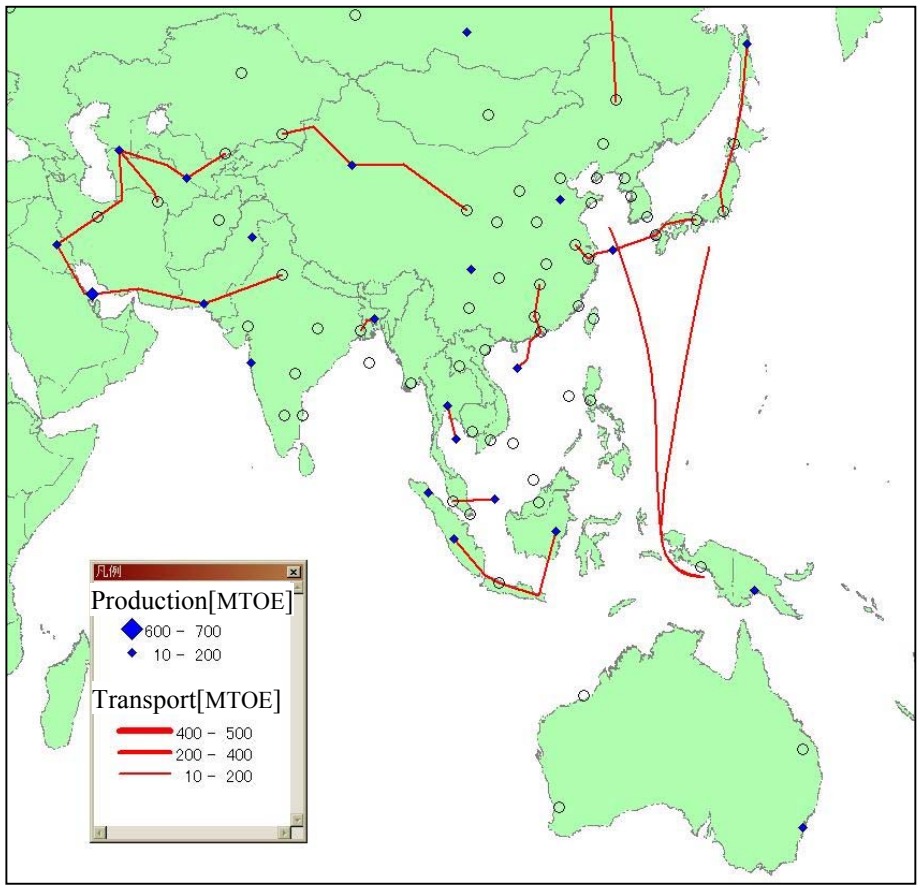


Production Profile in Asia

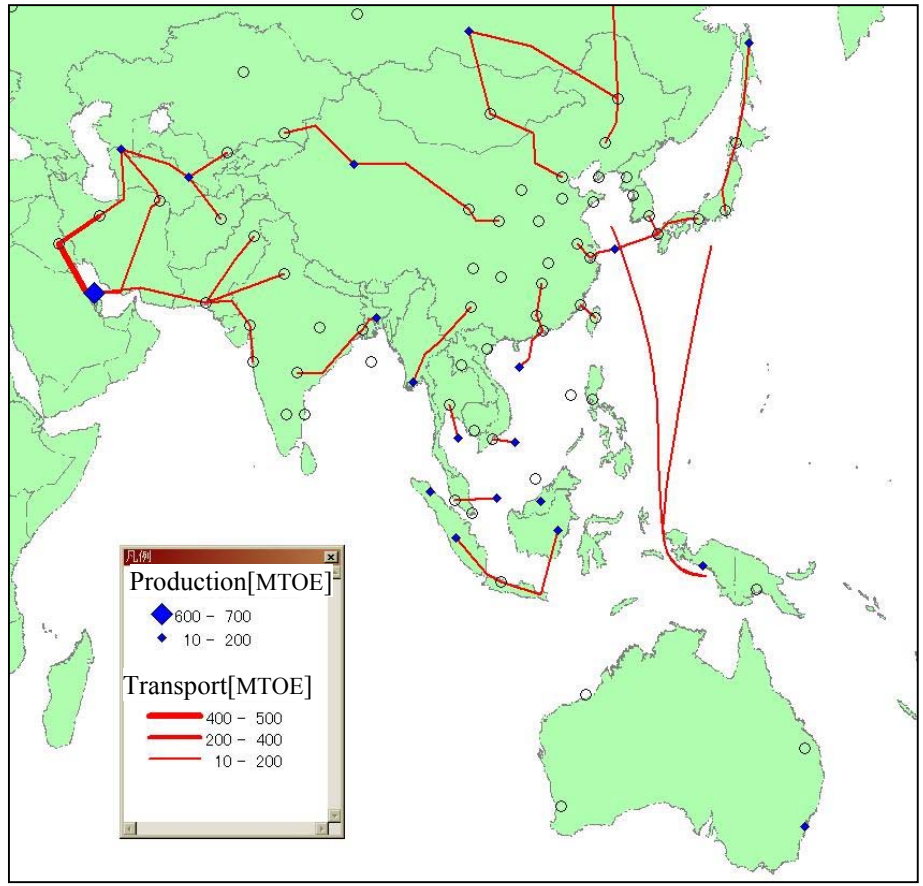


Year of 2010

Natural Gas (BAU)

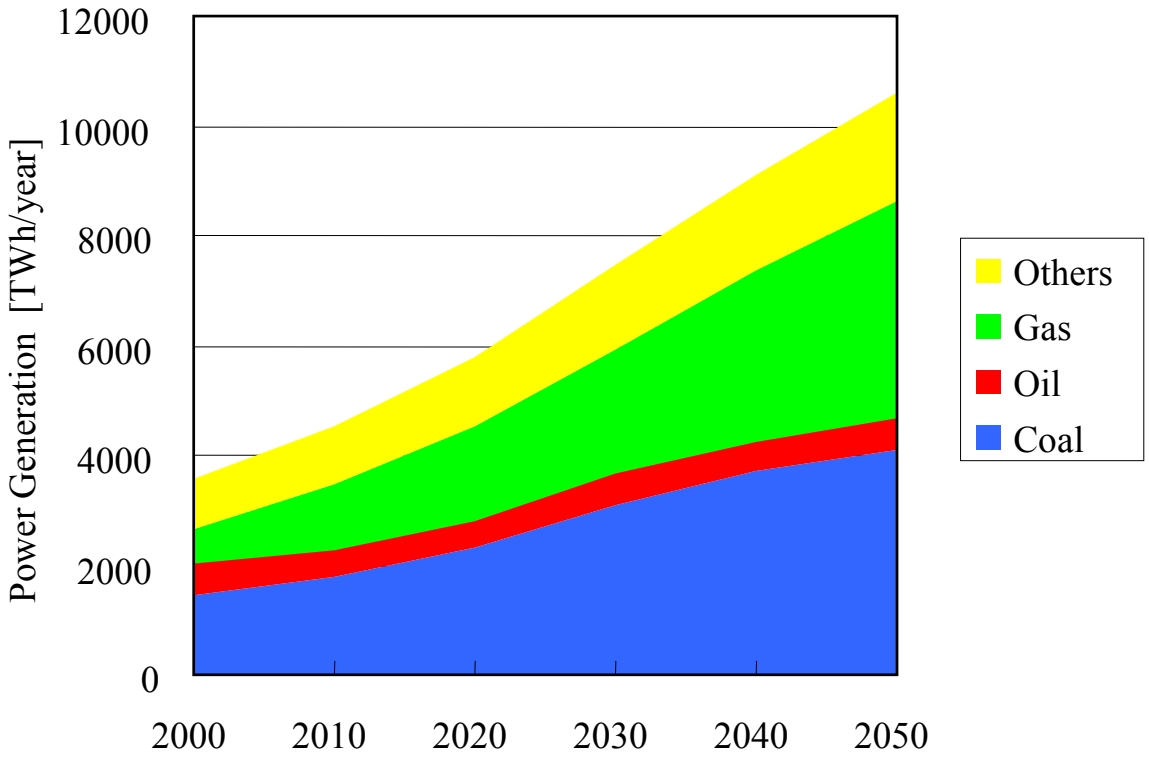


Year of 2030



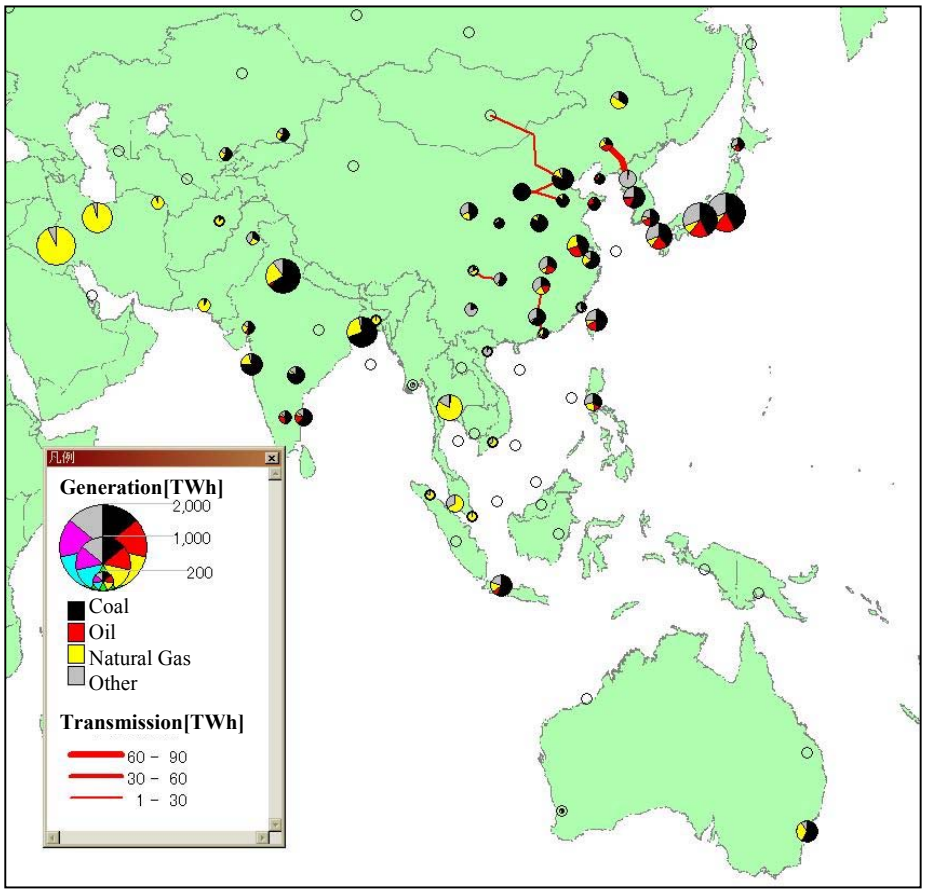
Year of 2050

Power Generation (BAU)

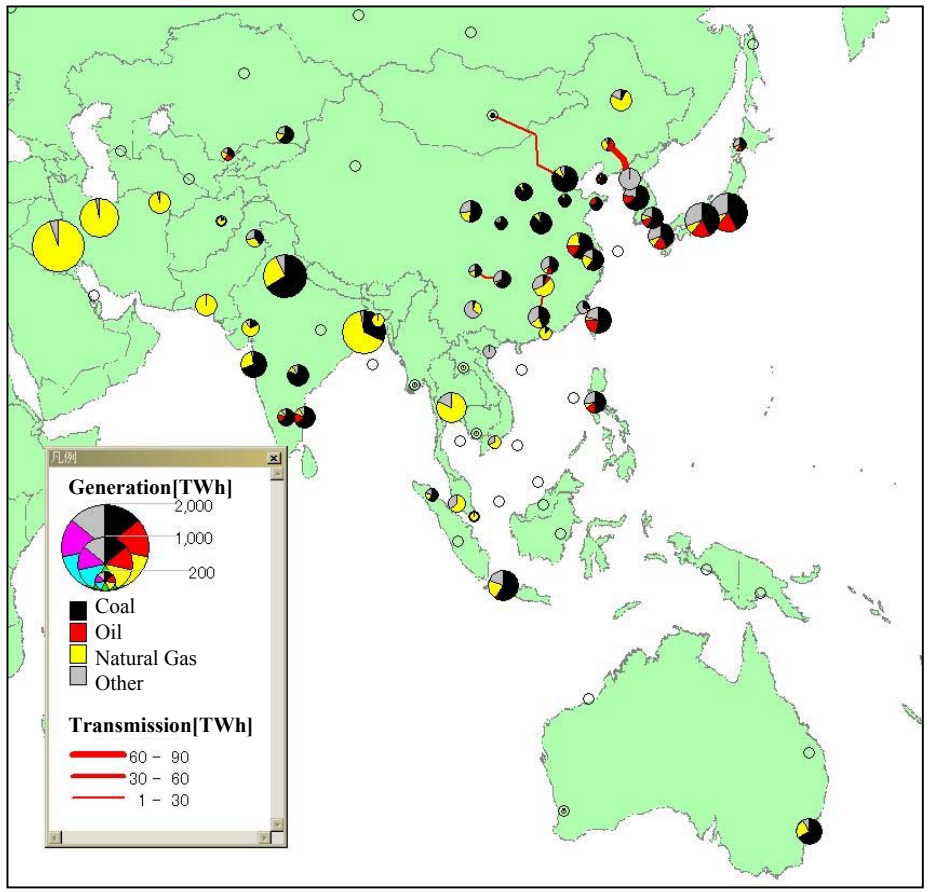


Power Generation Profile in Asia

Electricity (BAU)

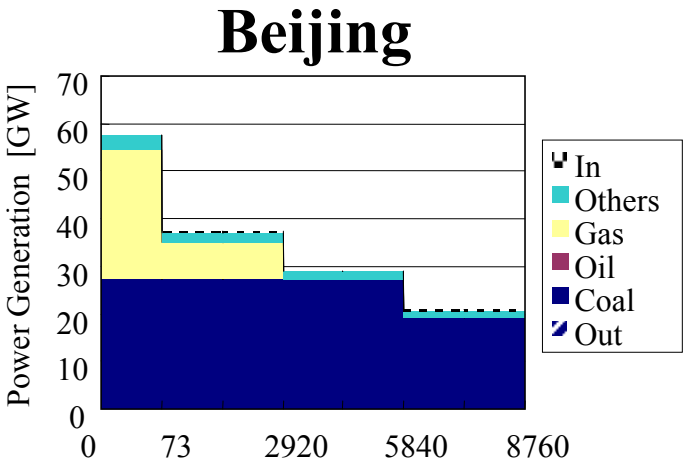


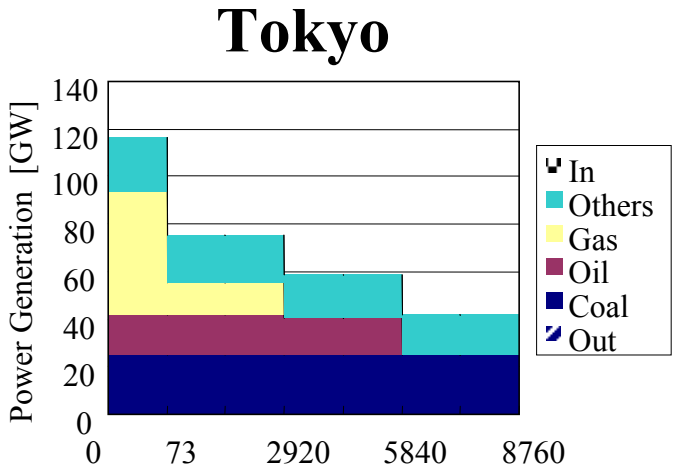
Year of 2030

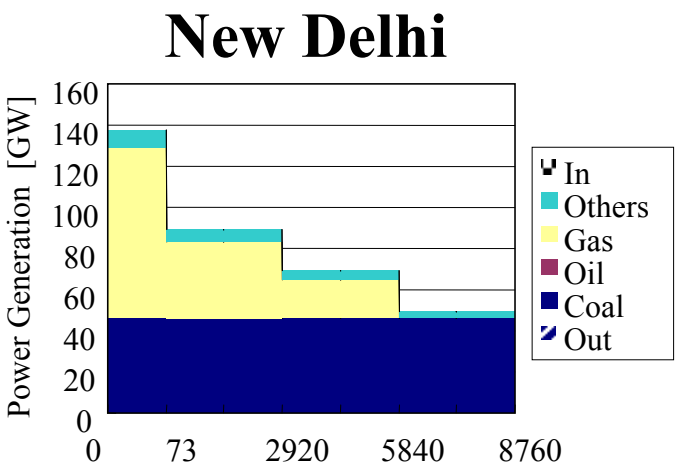


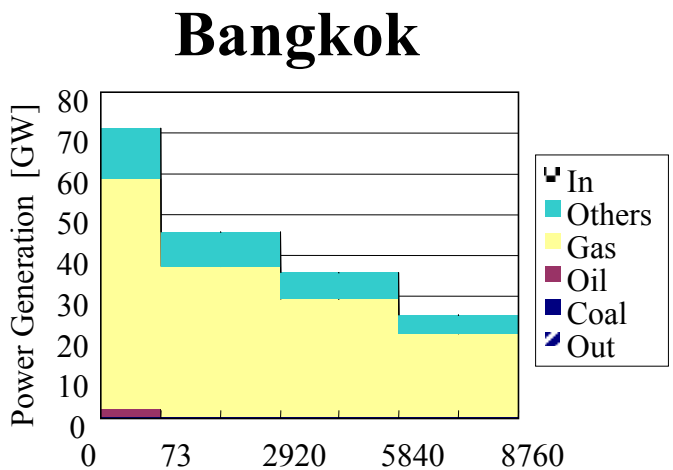
Year of 2050

Generation in 2050 (BAU)

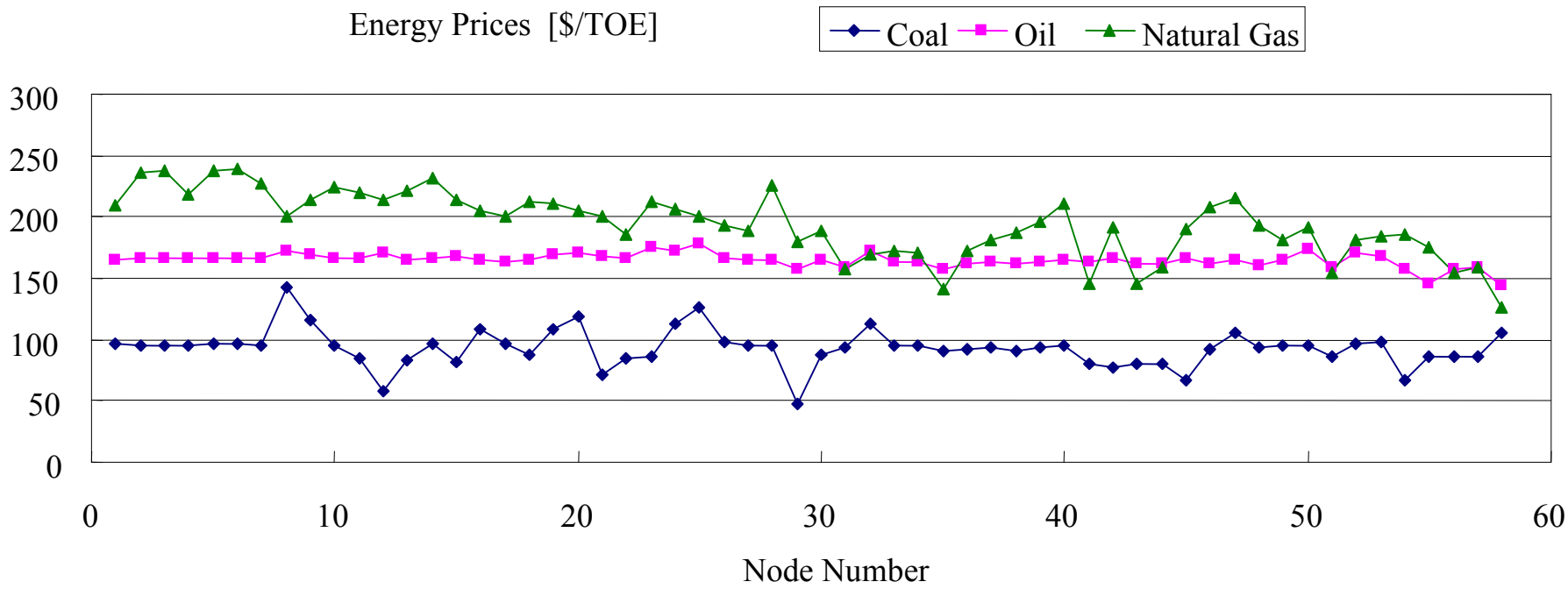




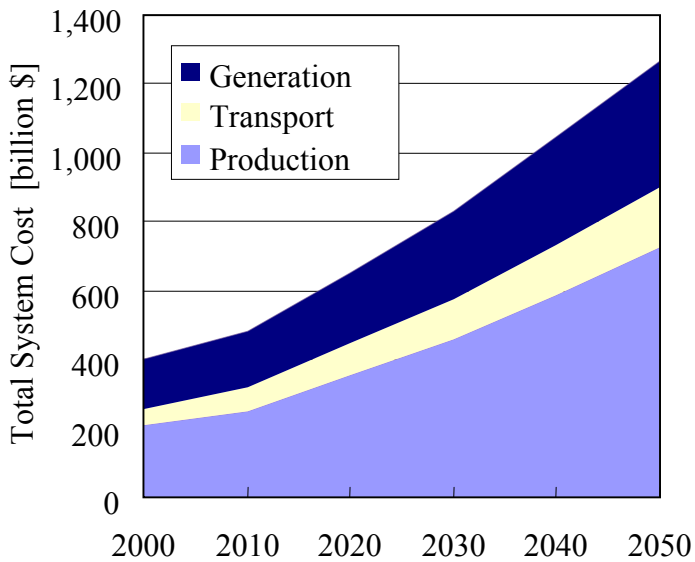


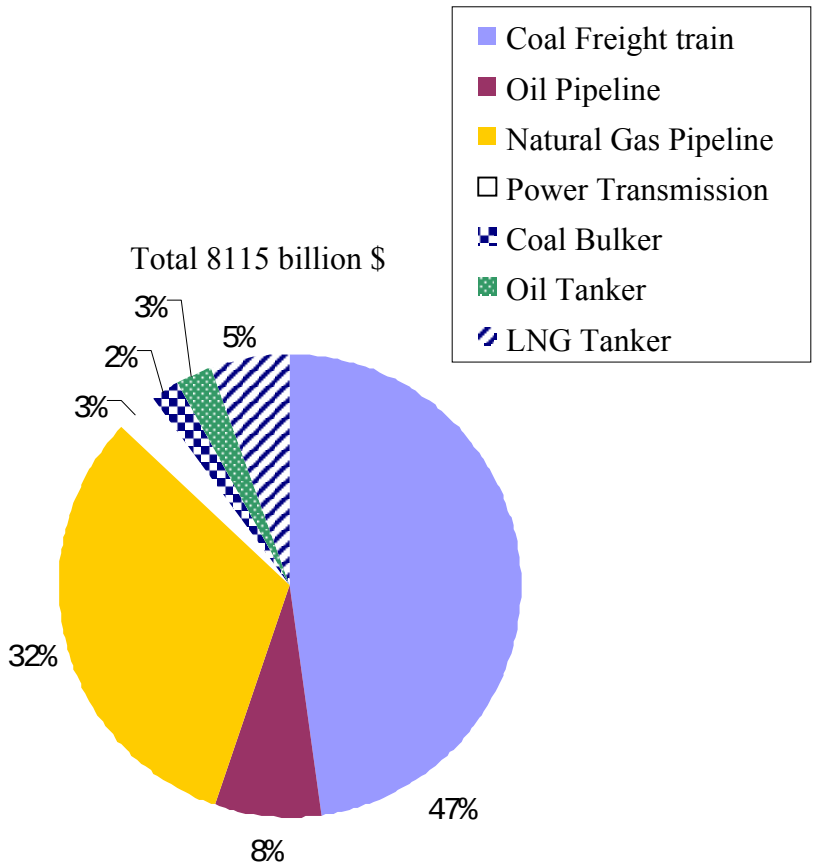


Energy Prices in 2050 (BAU)

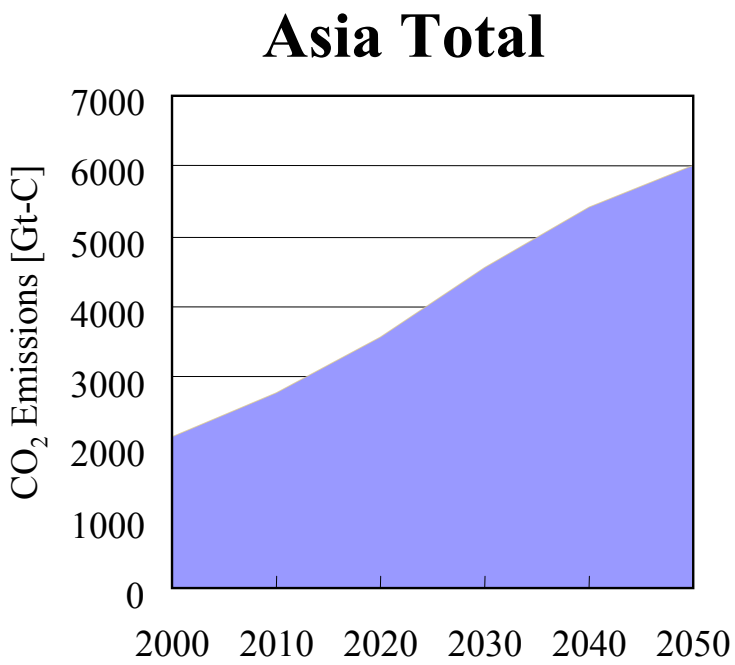


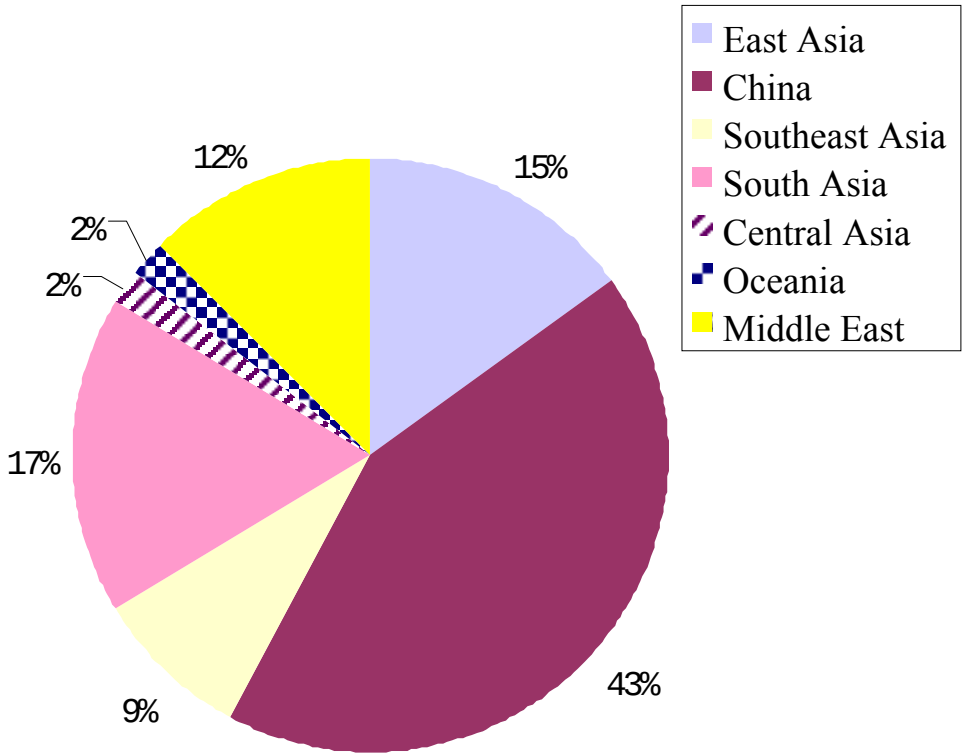
Total System Cost (BAU)



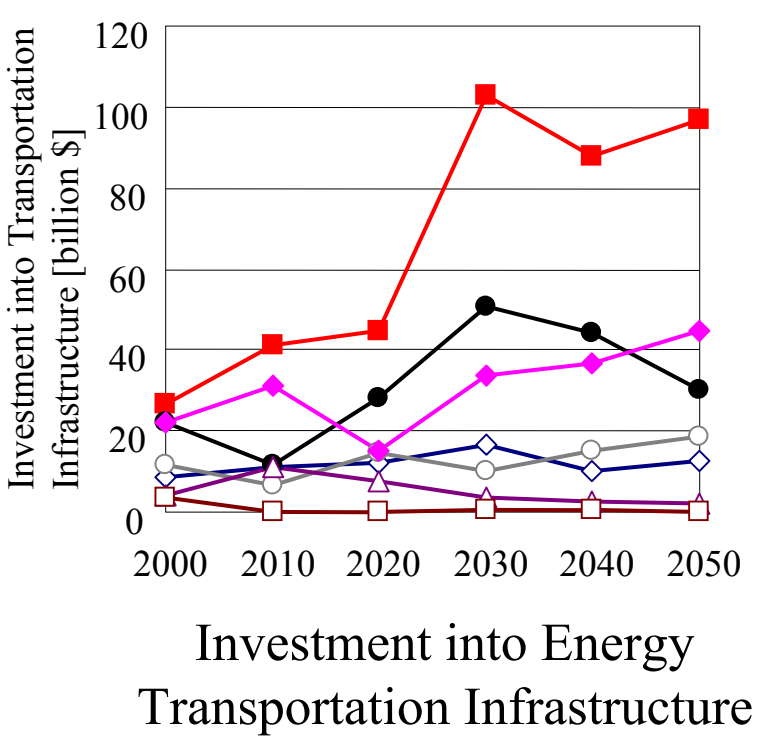


CO_2 Emissions in Asia (BAU)

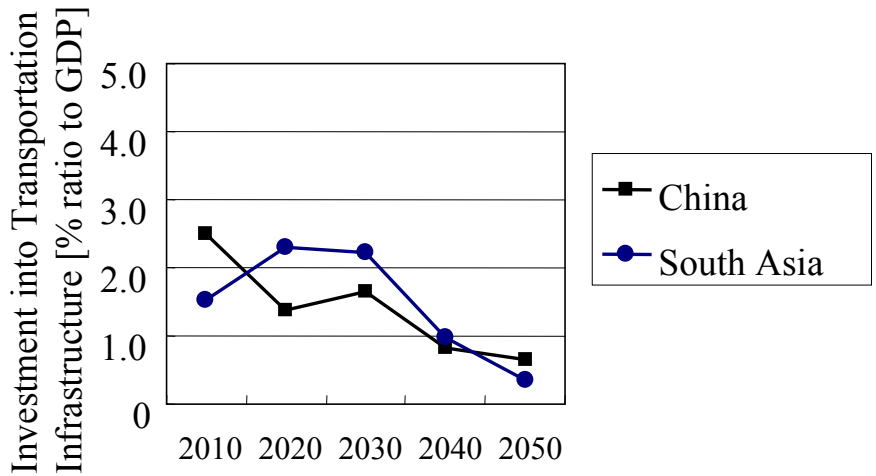




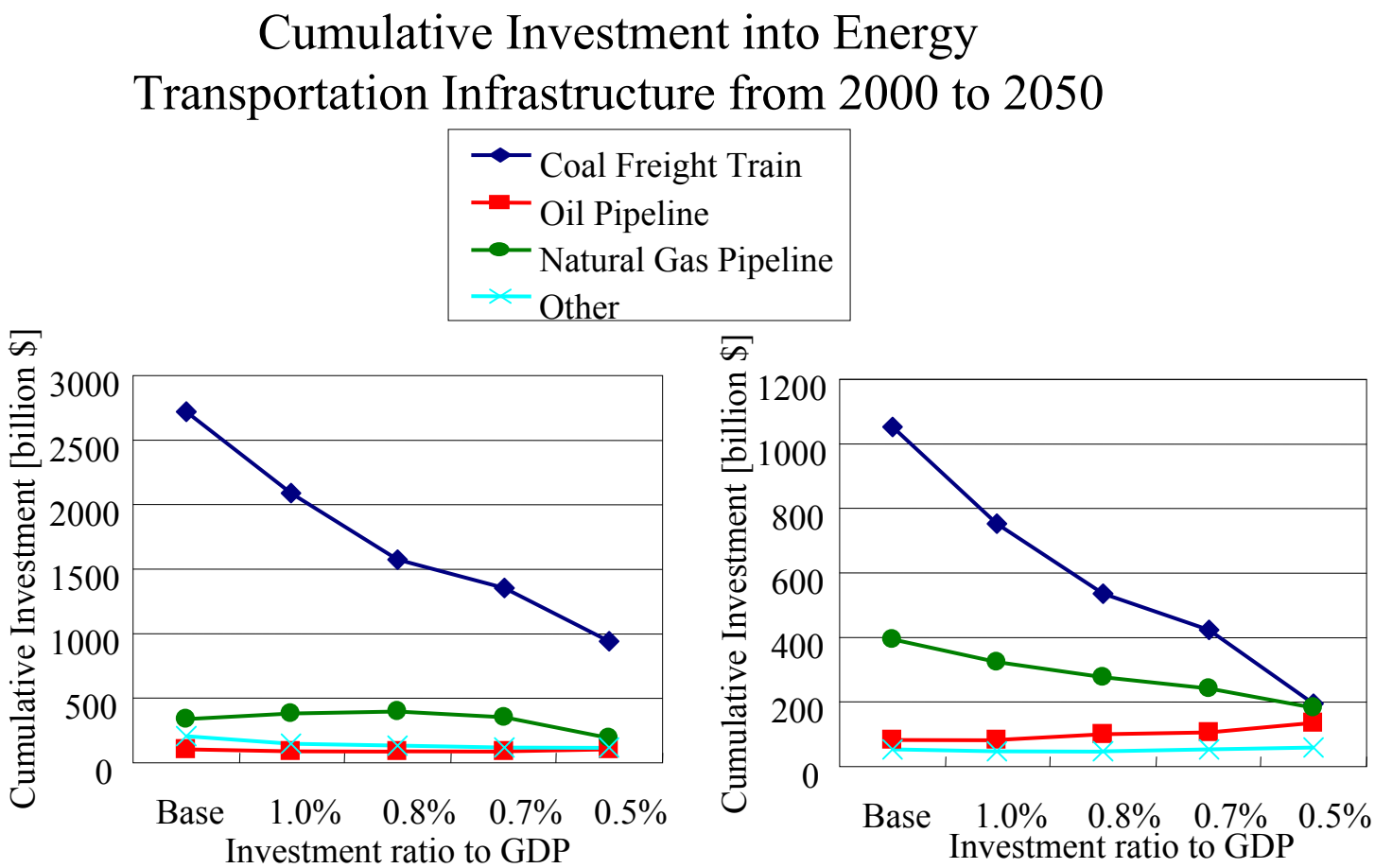
Investment (BAU)



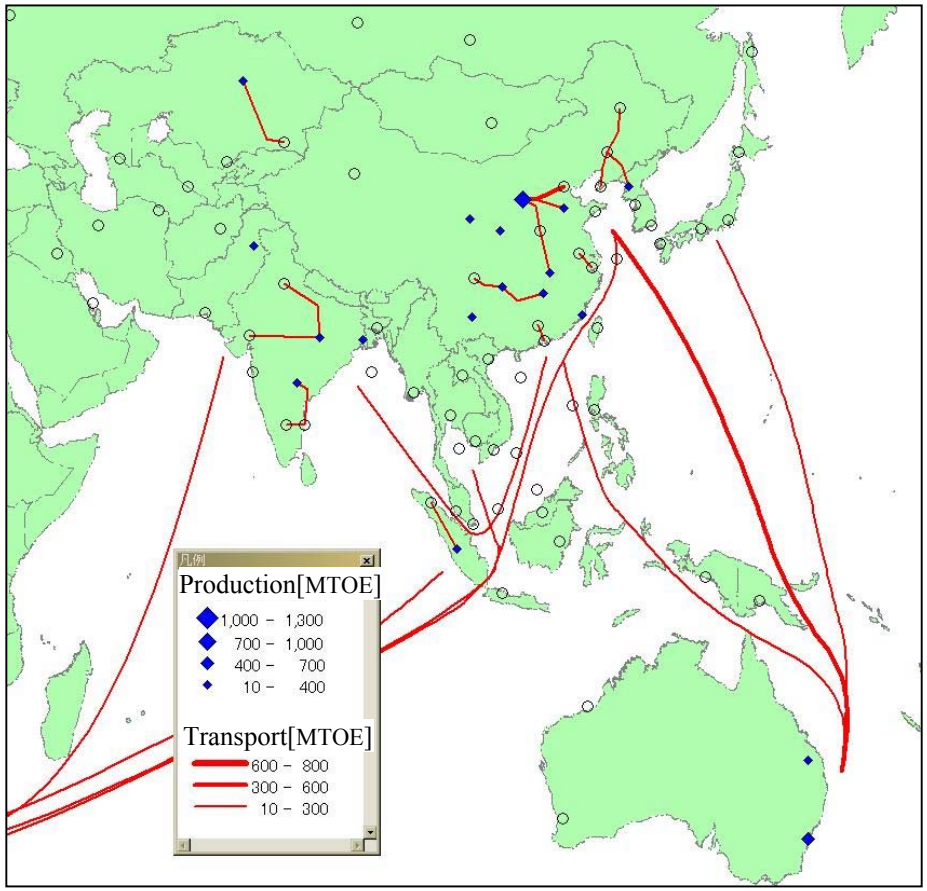
Investment into Energy Transportation Infrastructure



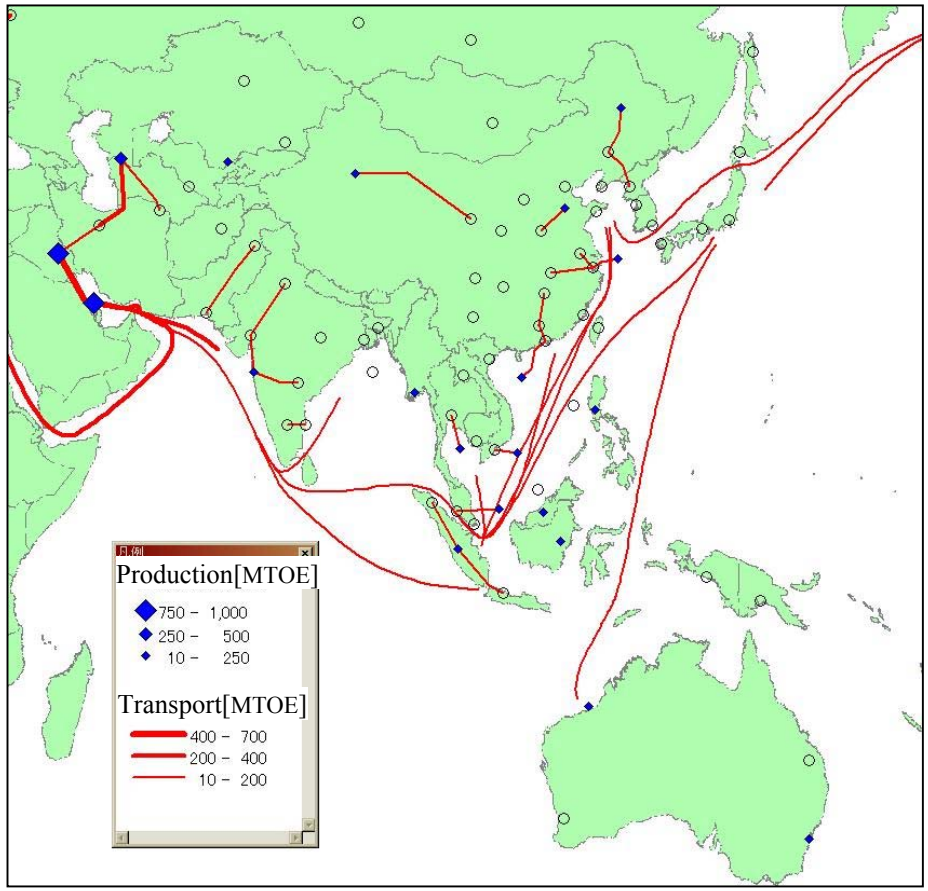
Changes in Investment Pattern



Coal and Oil in 2050 (ICC 0.7%)

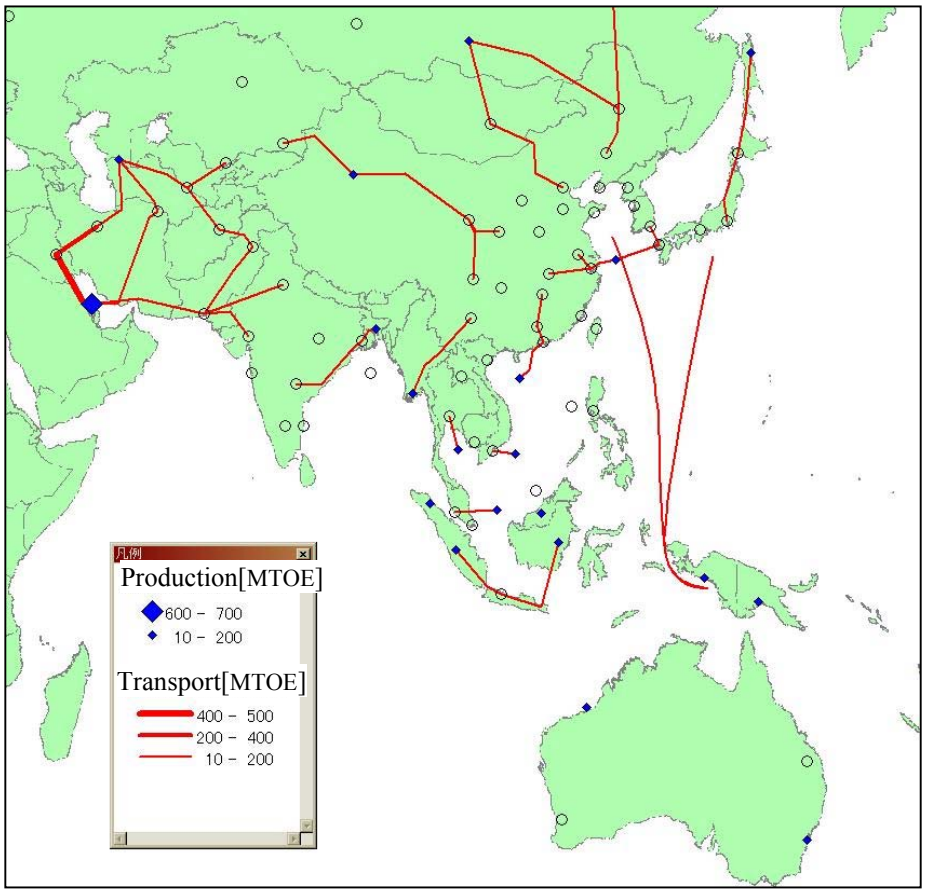


Coal

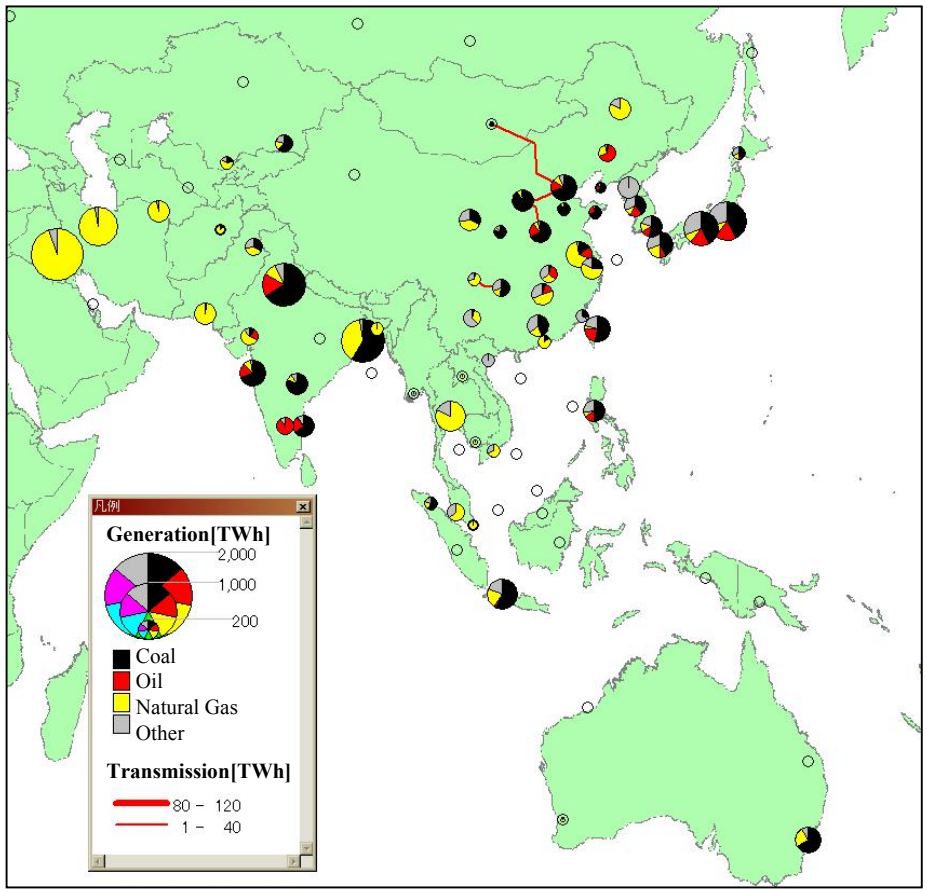


Oil

Nat.Gas and Elec.in 2050 (ICC 0.7%)

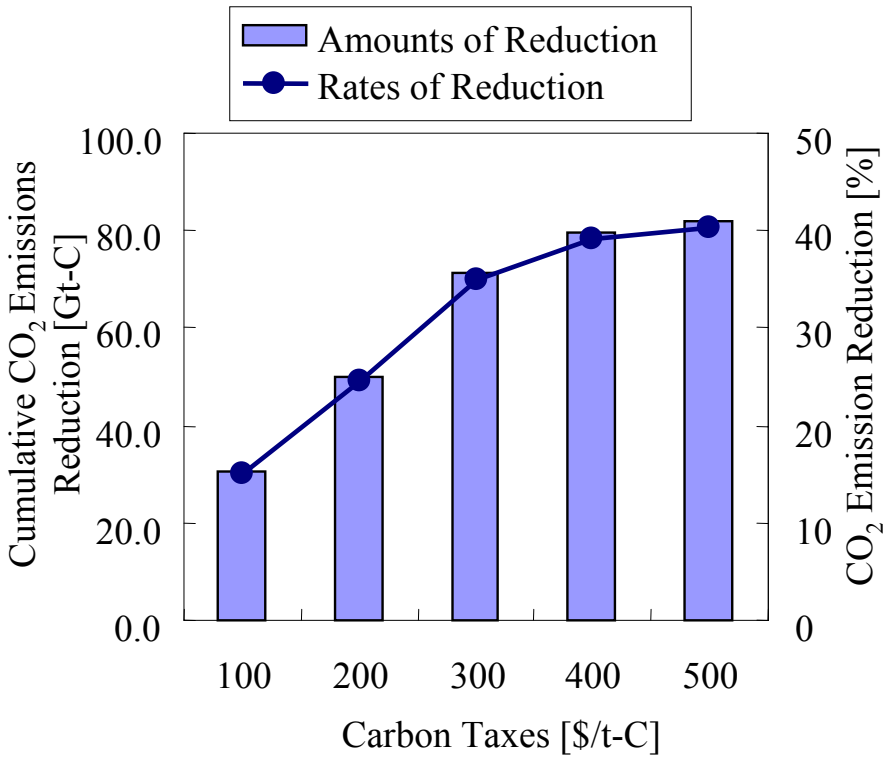


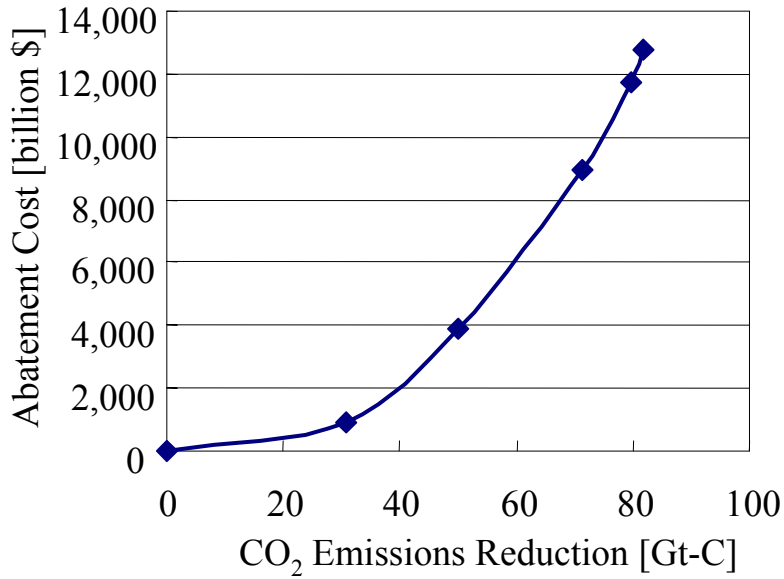
Natural Gas



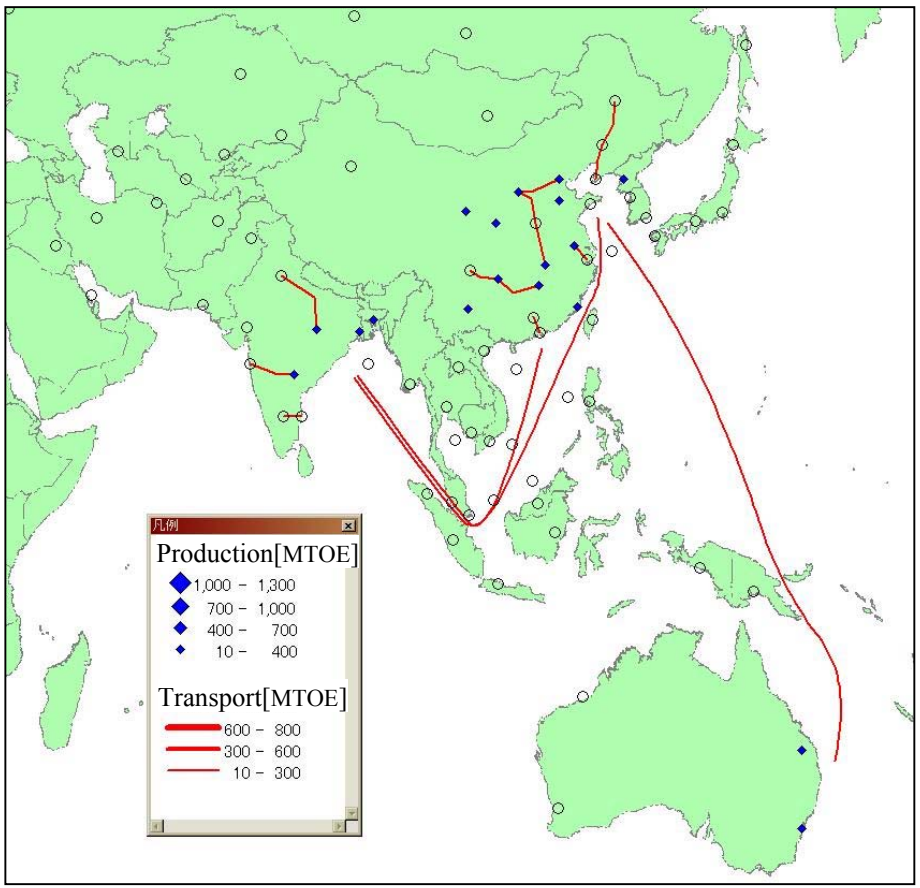
Electricity

CO_2 Emissions Reduction (CCC)

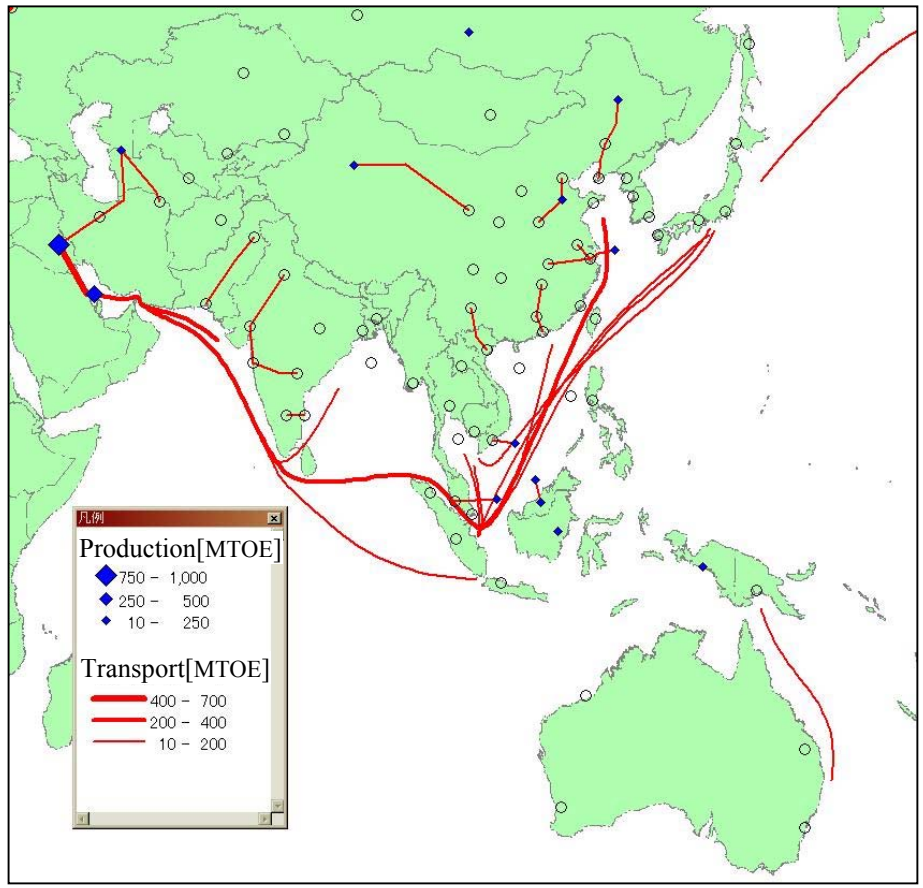




Coal and Oil in 2050 (CCC 300$/t-C)

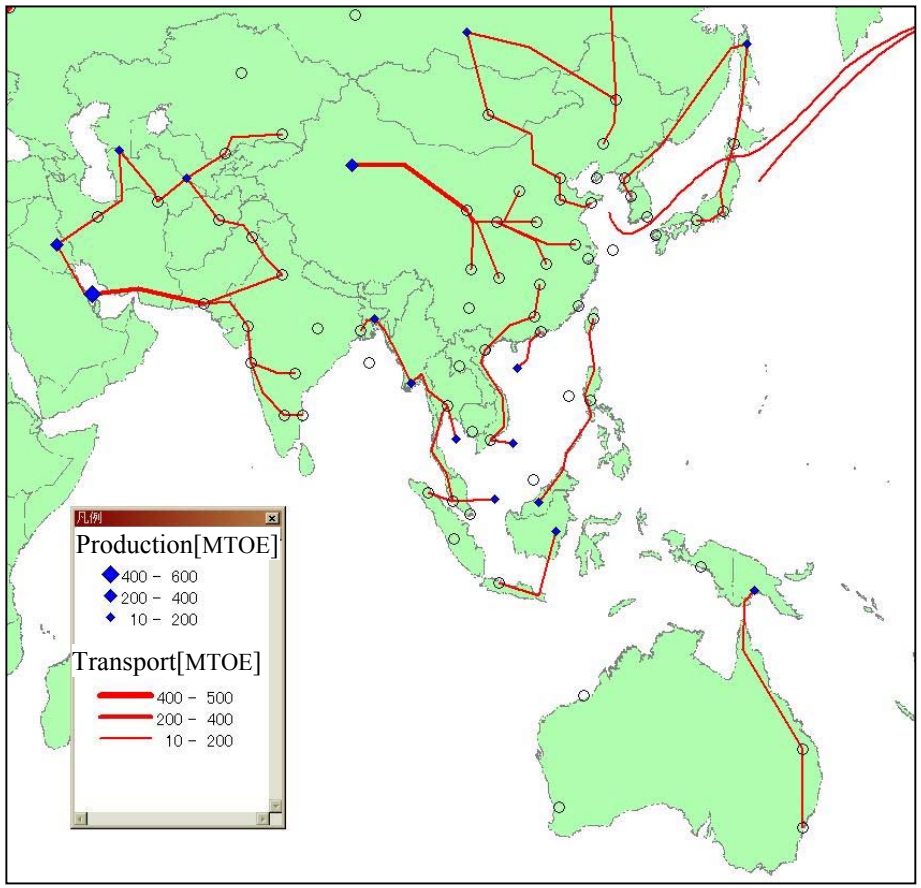


Coal

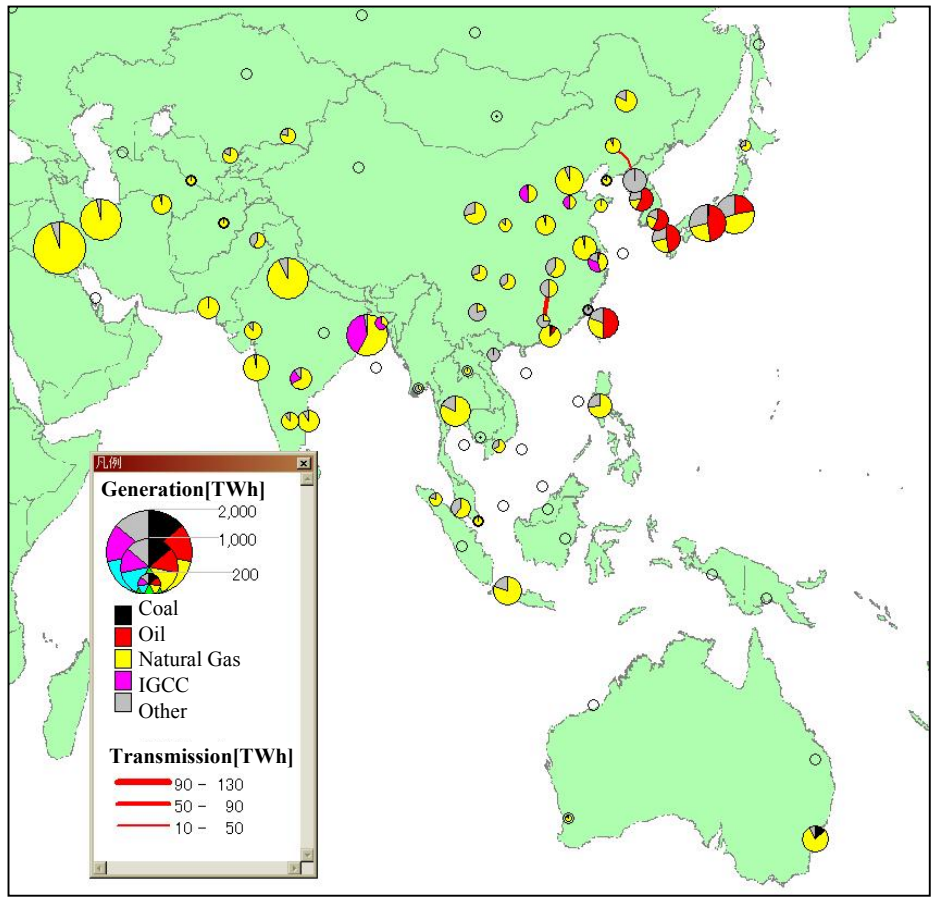


Oil

Nat.Gas and Elec.in 2050 (CCC 300$/t-C)

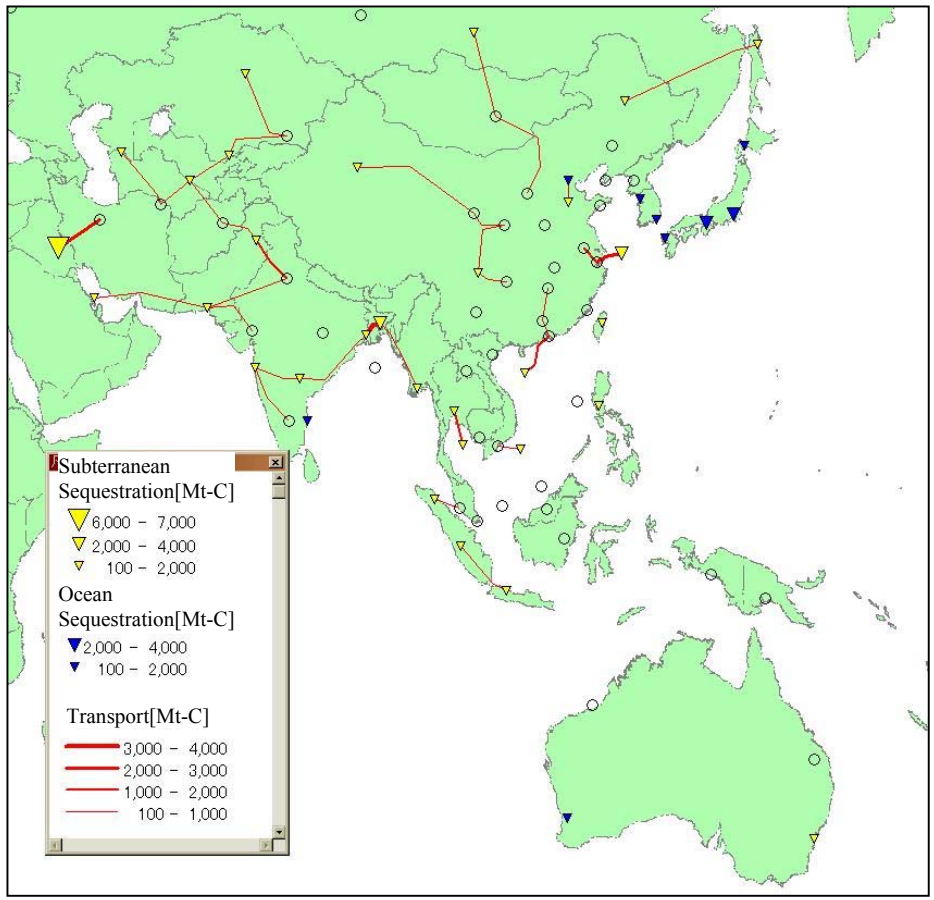


Natural Gas



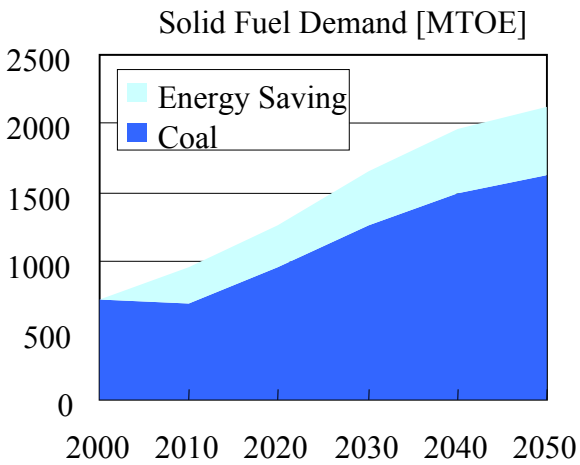
Electricity

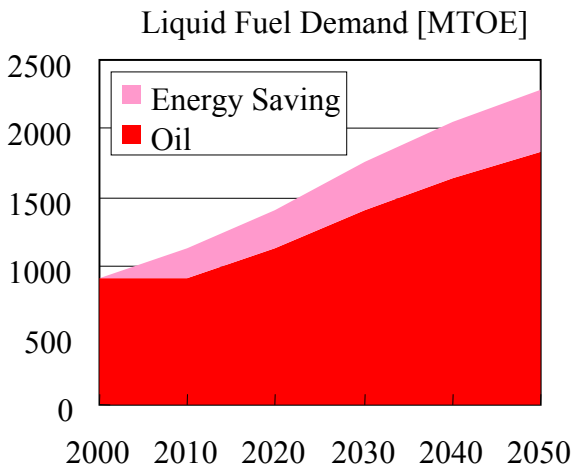
CO_2 Sequestration (CCC 300$/t-C)

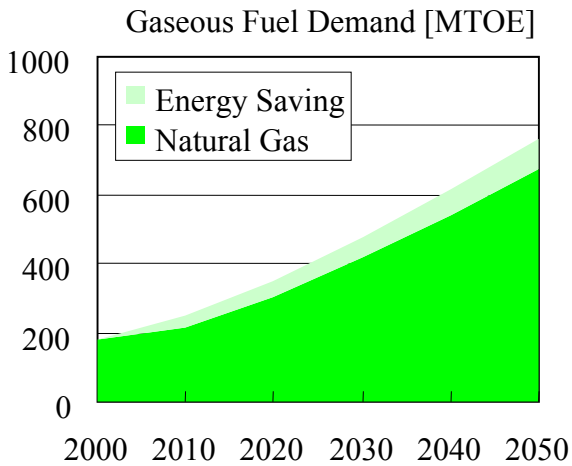


Cumulative Amounts of CO_2 Sequestration

Energy Saving (CCC 300$/t-C)



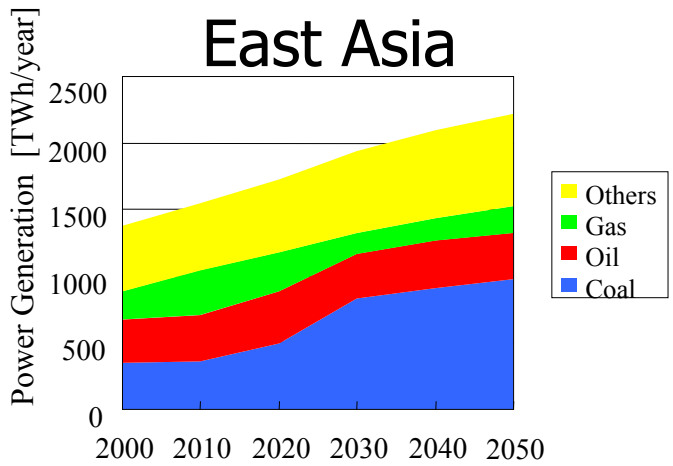


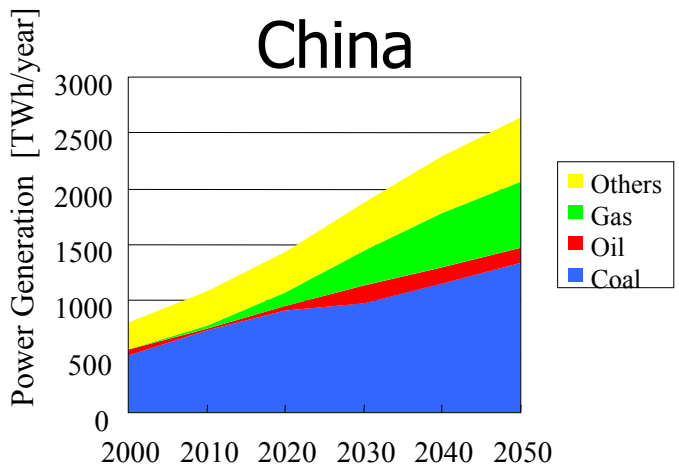


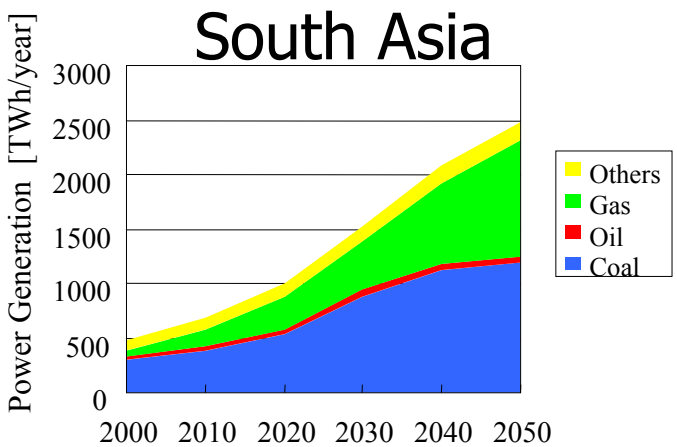
Concluding Remarks

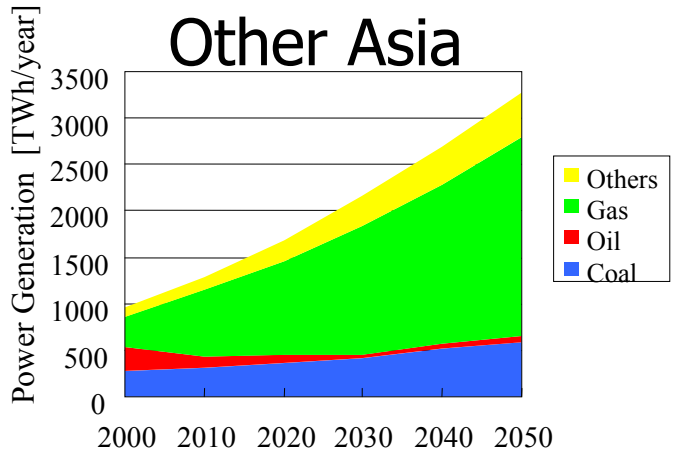
- In BAU case, coal is to be the dominant primary energy source, especially for power generation, and natural gas is to become the second most important primary energy.
- The necessity of the development of region-wide electricity grids is not obvious among Asian countries. However, in some cases, we can find a few of inter-city routes of power transmission lines as an optimal solution of the model.
- Investment constraints on energy transportation infrastructure in Asian countries may lower the use of domestic coal, and raise the degree of dependence to oil and natural gas, as well as imported coal.
- In CO_2 constraint case, the model estimated that an extensive network of natural gas pipelines is developed in China and East Asia.
- Neither the investment constraint nor the CO_2 constraint seem to have a significant influence on the optimal configuration of region-wide electricity grids.

Power Generation (BAU)









Power Generation (ICC 0.7%)